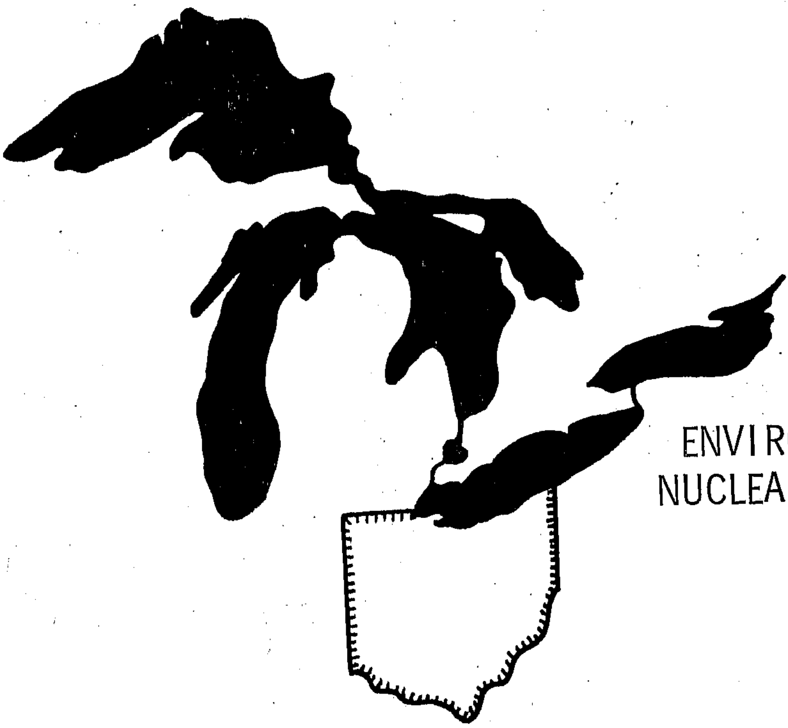
CLEAR TECHNICAL REPORT NO. 151



ENVIRONMENTAL EVALUATION OF A NUCLEAR POWER PLANT ON LAKE ERIE

FINAL REPORT - 1975
STUDY III
F-41-R-5 and F-41-R-6

Prepared for

U. S. Fish and Wildlife Service
and
Ohio Department of Natural Resources
Division of Wildlife

Prepared by

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THE OHIO STATE UNIVERSITY
CENTER FOR LAKE ERIE AREA RESEARCH
COLUMBUS, OHIO

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FEDERAL AID IN SPORT FISH RESTORATION

ANNUAL PERFORMANCE REPORT
Studies I & II
June 1, 1974 - May 31, 1975

FINAL REPORT
Study III
June 1, 1973 - May 31, 1975

PROJECT F-41-R-6

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THE OHIO STATE UNIVERSITY
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July 1975

FEDERAL AID IN SPORT FISH RESTORATION

FINAL REPORT

STATE OF:	Ohio
PROJECT NO.:	F-41-R-5, 6
PERIOD COVERED:	June 1, 1973 - May 31, 1975
DATE:	July 31, 1975
STUDY NO.:	III
STUDY TITLE:	Model Development for Determination of Fish Reactions to Thermal Plumes
PREPARED BY:	David C. Robb and Charles E. Herdendorf

Center for Lake Erie Area Research
The Ohio State University

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OBJECTIVES

This study is to provide a comprehensive model of fish response to thermal discharges. The model is to assess the influence of selected variables on fish distribution and response, should be easily used and modified, and present results in a readily understandable format. Furthermore, the model is to be applied to existing data on fish thermal response to furnish information on normal response patterns in standard conditions to facilitate application of the model.

ABSTRACT

A one-dimensional time dependent model of fish response to thermal discharges is presented. Incorporated in the model are provisions for thermal preference, thermal adaptation rates, current effects, nonlinearities in the thermal gradient, and to a limited extent, entrainment. Model results for several species indicate that: 1) The primary limiting factor in the proposed Davis-Besse system is the exit velocity. Fish are unable to swim against the induced current to reach temperatures more than about 1°C above ambient. 2) The greatest effects on fish distribution should be observed in winter. At that time, fish are projected to congregate in the warmest water available consistent with swimming ability. This region of congregation is expected to cover a large area beyond the 1° isotherm. During other times of the year, fish density in the region is projected to be at or below lake density.

A user's manual and documentation are provided to permit manipulation of the model for projecting unusual conditions or for new or untested species.

BACKGROUND

Due to the pervasive nature of temperature effects on nearly all aspects of fish physiology and behavior, this section is broken into a number of subsections, each dealing with a particular aspect of thermal influence. In addition, this section will provide information on efforts to treat some aspects of thermal influence in a theoretical manner, generally in terms of modeling. Finally, models of the physical characteristics of a plume regime will be reviewed.

Thermal preference

It is well established that fish will exhibit a preference for waters of a particular temperature. The temperature preferred is a function of species, and seems to be independent of the environment from which the species was obtained. Since the mid 1930's various authors have measured preferred temperatures of various species. A large portion of this data has been collected and tabulated in the Fisheries Handbook of Engineering Requirements and Biological Criteria (Bell, 1973.)

Two aspects of thermal preference should be noted. First, preference is an acclimative phenomenon. (Doudoroff, 1942; Brett, 1944) That is, the temperature preferred by a fish of a given species is dependent on both the temperature of the water and length of exposure prior to the preference test. Ultimately, some final preferred temperature is obtained and no exposure to water in excess of this will elevate the preferred temperature further. Second, so long as the maximum temperature of the environment is less than the final preferred temperature, fish will acclimate to the maximum rather than the mean temperatures of the environment. (Brett, 1944, 1946)

Temperature and fish distribution

Having established that fish prefer certain environmental temperatures over others, it remains to be shown how this influences their distribution in the aquatic environment.

Ferguson (1958) perfomed a series of experiments on yellow perch (*Perca flavescens*) in which the fish were permitted to distribute themselves freely in a vertical temperature gradient. Variations of the gradient were made and the results of the distribution noted. In all cases it was found that the majority of fish distributed themselves in waters of approximately 25°C. This corresponded well with other measurements of the final preferred temperature. Field studies performed by Dendy (1948) and Bardach (1955) indicate that this temperature selection phenomenon governs the distribution of fish in all regions where there is sufficient oxygen. In cases where the preferred temperature lay in a zone depleted in oxygen, the fish would distribute themselves as close to the preferred temperature as oxygen levels would permit. This would indicate that temperature is one of the prime determinants of fish position in the aquatic environment.

Temperature and swimming ability

Brett, et al. (1958) measured the swimming speeds of young coho and sockeye salmon at various temperatures. It was found that swimming speed (maximum sustained swimming speed) increased with temperature until some particular temperature was reached, after which swimming speed declined with increasing temperature. The point of inflection was unique for the species tested and was found to correspond to the preferred temperature of the species. This preferred temperature would seem to represent some metabolic optimum.

Swimming speeds of other species have been measured and results of several studies are presented in Fry (1967). Here also, peaking of swimming speed is observed at the preferred temperature of the species.

Lethal effects of temperature

Numerous authors have reported the lethal effects of both hot and cold water on fishes. Results of several of these studies are collected in Brett (1956). It has been found that the ultimate lethal limits (usually the points of 50% mortality) are characteristic of species. Lethal limits have been shown to vary with acclimation temperature and exposure time. Generally, both upper and lower lethal limits increase with increasing acclimation temperature and decrease with increasing exposure time. Data from Reutter (1972, 1973, 1974) indicates that cold shock (exposure to water colder than the lower lethal limit) is most critical due to the extremely rapid mortality. This sensitivity to cold shock has also been noted by other authors and is reported in Brett (1956).

Directive effects of temperature

Changes in temperature have been implicated as stimulative agents for such processes as sexual development, spawning and migration. Sensitivity of fish to temperature changes less than .1°C in magnitude have been demonstrated. Thermal selection in temperature preference studies has not demonstrated this degree of sensitivity, but apparently the response here is not as critical as for developmental or other responses. References to reports of various directive influences of temperature are presented in Brett (1959.)

Current effects on fish movement

Brett, *et al.* (1958) discussed the ability of fish to cope with currents. It was determined that as current increased, the range of temperatures within which fish could cope with the current decreased. This was due to the relation between swimming speed and temperature and consequently, the relation between metabolic activity and temperature.

Elson (1939) examined the behavioral response of speckled trout to current and variations in current. Fish activity was found to increase in regions of turbulence. High temperature was found to adversely affect activity. Fish were also allowed to select between regions of high and low current. The fish were found to select regions of reduced current but not regions of eddy or still water. Once a particular set of conditions was selected, the fish tended to maintain position and exhibited little tendency to wander. Random wandering activity was highest in still water.

Thermal plumes: studies and models

Studies of thermal plumes have recently become popular and there is rapid proliferation of information on theoretical and phenomenological aspects of plume generation, structure and propogation. Only a few representative studies will be discussed here.

Two recent studies of thermal plumes (Frigo, et al. 1973; Green, et al. 1972) illustrate several characteristics of thermal plumes. Thermal imagery used by Green, et al. vividly illustrates the surface temperature distributions in thermal plumes. One obvious feature of the distribution is the thermal banding which occurs throughout the plume. This thermal banding is a periodic (with distance) phenomenon probability created by instability and oscillation in the jet. It is readily seen on thermal infrared photographs as a series of alternating light and dark arcs extending outward like ripples from the plume source.

Subsurface measurements were made to determine if this banding was limited to the surface or whether it extended throughout the depth of the plume. It was found that the surface observations reflected conditions at depth, that is, the observed temperature band extended down from the surface to the bottom of the plume. Thermal variation near the outlet was found to be periodic in time with a peak to peak amplitude of 2-3°C and a frequency of approximately three cycles per minute.

Paddock, et al. (1973) discuss various mathematical models of thermal discharge plumes and evaluate model accuracy in prediction of real conditions. The general conclusion reached is that the physical models are progressing well and in most cases give good approximations to observed conditions; however, further effort is required before the models can be considered of high reliability.

Fishery models

Most models of fish populations and fisheries deal with mass or energy flows through the environment. Very few deal with behavorial response to change in environmental conditions.

An example of the first type is the model of Riffenbaugh (1969.) In this model a three fishery system was considered. Interactions between species, fisheries and predators were considered and used to develpp an optimum strategy for management of the fisheries. Verification of the model was achieved by comparison of model predictions with several year's previous data of abundance, fishing effort and yield. Agreement was very good.

The only example known to this author of the second type model is the current model study.

PROCEDURES

I. Data Reduction

The available data on fish motion in a thermal gradient was insufficient to apply the more common methods of analysis in formation of a model. Thus it was necessary to devise a method of extracting the maximum information from existing data and then expanding this via an intermediate model.

Inspection of a large number of sets of observations on fish distribution in a thermal gradient indicated that the distribution could be approximated by a skewed-normal probability function. The equation used to model this probability function is given below.

$$P_{(T)} = \frac{1}{\sigma\sqrt{2\pi}}\, e^{-\left[(T-T_m)^2/2\sigma^2\right]\quad\left(e^{b\,(T-T_m)}+1\right)/2}$$

The standard deviation $\underline{\sigma}$ and the mean thermal adaptation temperature $\underline{T_m}$ (which equals the preferred temperature under steady state conditions in the test gradient) were determined directly from the experimental data. These sample statistics were considered to be efficient estimators of the corresponding population statistics. The skewing factor $\underline{b}$ was determined by fitting this distribution model to pooled observations made after steady state conditions were achieved, that is, after the mean position of the fish in the test gradient showed no significant variation with time.

A description and listing of the program used to obtain $\underline{\sigma}$, $\underline{T_m}$, and $\underline{b}$ is given in appendix I.

The function was chosen because it has a number of desirable properties, notably,

$$\lim_{T \to \pm \infty} P_{(T)} = 0$$

and

$$\lim_{b \to 0} P_{(T)} = \frac{1}{\sigma\sqrt{2\pi}} \; e^{(T-T_m)^2 / 2\pi^2}$$

which is simply the equation of a Gaussian Normal distribution. Also the function is approximately normalized, that is

$$\int_{-\infty}^{+\infty} P(T)dT \cong 1$$

In order for the equality constraint to hold, P(T) as given should be multiplied by a normalization factor for a particular combination of $\underline{\sigma}$ and $\underline{b}$. However, in most cases $\underline{b} << 1$ and the value of the normalization constant does not thus differ significantly from 1.

II. The kinetics model and rate determination

For this second step, the motion of the fish in the gradient was assumed to be a Poisson process where in some time increment $\underline{\Delta t}$ the fish had a set of probabilities such that there could be a transition to the next highest temperature, the next lowest, or no transition. The time increment Δt was presumed small enough that a transition of more than one thermal state was highly improbable. The transition probabilities were given by

$$P_{i \to j} = \begin{cases} j > i, & \lambda_i \Delta t \\ j = i, & (1 - \lambda_i \Delta t)(1 - \mu_i \Delta t) \\ j < i, & \mu_i \Delta t \end{cases}$$

A derivation of the process is as follows. P(i, t) is the probability of a fish occupying state i at time t.

$$\begin{aligned} P(i, t+\Delta t) = {} & P(i, t)(1 - \lambda_i \Delta t)(1 - \mu_i \Delta t) + \\ & P(i+1, t)(\mu_{i-1} \Delta t) + \mathcal{O}\sum_{j=2}^{n} P(i+j, t)(\mu_{i+j} \Delta t) \\ & + P(i-1, t)(\lambda_{i-1} \Delta t) + \mathcal{O}\sum_{j=2}^{n} P(i-j, t) \\ & (\lambda_{i-j} \Delta t) \end{aligned}$$

The system is severely limited by the swimming speeds and current velocities. This implies that in some given time increment the probability of swimming some distance greater than a distance equal to the vector sum of swimming velocity and current velocity times the time increment is very small. Appropriate choice of the time increment can thus maximize one step transition probabilities without significantly increasing two step or greater transition probabilities for some given distance between states. Assuming such an appropriate time increment Δt, the higher order terms in the above equation can be neglected leaving

$$
\begin{aligned}
P(i,\ t + \Delta t) = {} & P(i-1,\ t)\,(\lambda_{i-1}\,\Delta t) + P(i,t) \\
& - P(i,\ t)\,(\lambda_i + \mu_i)\,\Delta t + P(i,\ t)\,(\lambda_i\,\mu_i\,\Delta t^2) \\
& + P(i+1,\ t)\,(\mu_{i+1}\,\Delta t)
\end{aligned}
$$

subtracting $P(i,\ t)$ from both sides and dividing by Δt

$$
\begin{aligned}
\frac{P((i,\ t+\Delta t) - P(i,\ t)}{\Delta t} = {} & P(i-1,\ t)\,\lambda_{i-1} - P(i,\ t)\,(\lambda_i + \mu_i) \\
& + P(i,\ t)\,(\lambda_i\,\mu_i\,\Delta t) + P(i+1,\ t)\ \mu_{i+1}
\end{aligned}
$$

taking the limit as $\Delta t \rightarrow 0$

$$
\begin{aligned}
\frac{d\,P(i,\ t)}{dt} = {} & P(i-1,\ t)\,\lambda_{i-1} - P(i,\ t)\,(\lambda_i + \mu_i) \\
& + P(i+1,\ t)\ \mu_{i+1}
\end{aligned}
$$

taking $\{i\} = \{\text{all available states}\}$ one obtains a set of simultaneous differential equations describing fish motion in a thermal gradient.

Normally, the values of the $\underline{\lambda_i\text{'s}}$ and $\underline{\mu_i\text{'s}}$ would be obtained by direct observation of fish motion in the gradient. This would require an observer noting the time a compartment change occurred and the compartments of origin and destination for the fish tested over a several hour period repeated several times during the preference test. An experiment was attempted using time lapse photography to record these changes, but difficulties in fish identification, blocking by compartment walls and camera availability precluded use of this methods here. Lacking this information, it was necessary to assume general functional forms for $\underline{\lambda}$ and $\underline{\mu}$. It was known that $\underline{\lambda}$ and $\underline{\mu}$ were dependent on the adaptation temperature at the time of observation and that $\underline{\lambda}$, the rate of going to a higher temperature, should decrease with increasing temperature, and $\underline{\mu}$, the rate of going to a lower temperature, should increase with increasing temperature. The maximum rate in any case should not be greater than the swimming speed. It was also known that under steady state conditions where Tm = final preferred temperature, dP(T) / dt = 0, and that the rate functions selected should generate the observed steady state distribution.

These constraints suggest that the rate functions are of the form:

$$\lambda_j = \frac{Vs}{1 + e\left[(T_j - T_p)\left|T_j - T_p\right|(e^{b(T_j - T_p)} + 1) / 4\sigma^2\right]\delta}$$

$$\mu_j = \frac{Vs}{1 + e^{-}\left[(T_j - T_p)\left|T_j - T_p\right|(e^{b(T_j - T_p)} + 1) / 4\sigma^2\right]\delta}$$

where:

T_j = temperature of the j^{th} state

T_p = internal preferred temperature

$|T_j - T_p|$ = absolute value of the temperature difference

b = skewing factor

σ = standard deviation of steady state distribution

V_s = maximum sustained cruising speed

$\delta = \left.\frac{dT}{dx}\right|_j \Big/ \left.\frac{dT}{dx}\right|_*$ = ratio of temperature gradients

* - critical velocity point

It can readily be shown that as the i^{th} and $i \pm 1^{th}$ states get closer together, the functions given above yield improving approximations of the steady state distribution function, to the extent that for a continuous distribution of states, the functions yield the distribution exactly.

It should be noted at this point that due to the nature of the assumptions regarding the distribution function and the physical processes as well as limitations of the available data on thermal seeking and swimming behavior, it would be wise not to place too great a biological or physical significance on the derived functions. There are numerous other models which could yield similar results but would have greatly different structures and assumptions. In the absence of data to the contrary, however, this is a reasonable model of the process.

III. The time dependent distribution model

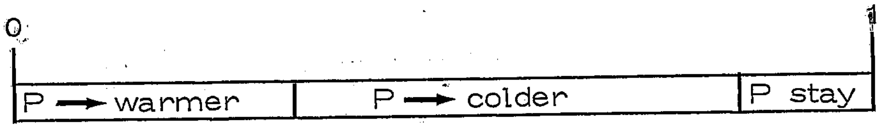
This model, which is listed and detailed in appendix III, is of the Monte-Carlo type and is executed as follows. The plume is first divided into a series of compartments of equal size. Since this model is presently one-dimensional, the compartments corresponde to equal distance along the plume centerline. Next, a time increment $\underline{\Delta t}$ is chosen such that the probability of a fish remaining in a particular compartment over that time increment is low, and also such that the probability of swimming through two or more compartments in that Δt is small. The appropriate Δt is readily calculated from consideration of the compartment size, swimming speed and current velocity. Then, given the rate functions, Δt, and current velocity, the transition probabilities are calculated by

$$P \rightarrow \text{warmer} = \frac{\lambda_i \Delta t}{\lambda_i \Delta t + \mu_i \Delta t + (1 - \lambda_i \Delta t)(1 - \mu_i \Delta t)}$$

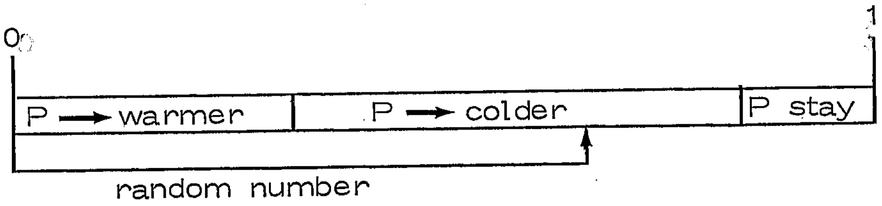
$$P \rightarrow \text{colder} = \frac{\mu_i \Delta t}{\lambda_i \Delta t + \mu_i \Delta t + (1 - \lambda_i \Delta t)(1 - \mu_i \Delta t)}$$

$$P \text{ stay} = \frac{(1 - \lambda_i \Delta t)(1 - \mu_i \Delta t)}{\lambda_i \Delta t + \mu_i \Delta t + (1 - \lambda_i \Delta t)(1 - \mu_i \Delta t)}$$

The λ's and μ's in this case are related to the λ's and μ's of the rate model by the addition or subtraction of the current velocity of the i^{th} compartment, the sign of the arithmetic operation being determined by consideration of whether warmer temperatures may be found upstream or downstream of the i^{th} compartment. The compartment designation $\underline{i}$ refers to the compartment where the fish of interest is located at the time of observation. A random number is then generated and compared to the transition probabilities to determine which transition occurs in that t increment. An example of how this works can be shown by the following example. The sum of the probabilities must, by definition of the process, sum to one. Thus the sum may be represented on a number line by



The random number generated lies between zero and one and is compared as below.



Since the random number of this example falls in the range of P → colder, a transition of the fish to the neighboring box of lower temperature occurs. The subscript is then updated, the elapsed time incremented by Δt, new rates for the new subscript are calculated and the internal preferred temperature is updated.

The internal preferred temperature curve is presumed to follow the experimental mean preferred temperature curve until such time as some barrier is reached, such as a compartment where the current velocity is equal to swimming velocity, but opposite in direction. The internal preferred temperature then remains slightly greater than the water temperature of that compartment. The position of the fish in the gradient is observed after various periods of time have elapsed, and this position recorded. When the pre-specified run time has elapsed (simulated time), the final position is recorded, all times and the interval preferred temperature are reset, and a new fish is started through the gradient. The process is repeated until the pre-specified number of fish have been run. The numbers of fish recorded in each compartment at the various times are then divided by the total number run to give the occupation probability. The steady state occupation probabilities and enhancement ratios are calcualted by a separate procedure in the following manner. First, the last compartment (#500) is presumed to be continuous with lake conditions. This implies that the enhancement ratio here will be equal to one. Second, it is known that under steady state conditions there must be no net change in the number of fish in any given compartment. This implies:

$$\mu_{i-1} \; P_{i-1} = \lambda_i \; P_i \qquad \text{or} \qquad \frac{P_{i-1}}{P_i} = \frac{\lambda_i}{\mu_{i-1}}$$

A series of equations can be generated in the following manner:

$$\frac{P_{499}}{P_{500}} = \frac{\lambda 500}{\mu 499} \qquad \frac{P_{499}}{P_{500}} = ER_{500} \equiv 1$$

$$\frac{P_{498}}{P_{500}} = \frac{\lambda 500 \cdot \lambda 499}{\mu 499 \cdot \mu 498} \qquad \frac{P_{498}}{P_{500}} = ER_{499}$$

$$\frac{P_{499-i}}{P_{500}} \quad \frac{\lambda 500 \cdot \lambda 499 \cdots \lambda 500-i}{\mu 499 \cdot \mu 498 \cdots \mu 499-i} \qquad \frac{P_{499-i}}{P_{500}} = ER_{500-i}$$

This is continued until i = compartment$_*$ where compartment$_*$ is the location of the critical velocity. Since fish cannot maintain position upstream of this point, the occupation probability is zero. The enhancement ratios (ER) are given explicitly by this method and the occupation probabilities are:

$$P_i \doteqdot \frac{ER_i}{\sum_{j=500}^{500-j*} ER_j}$$

This procedure is a random process simulation of fish behavior and yields the expected distributions of fish for a given set of conditions. Again, it is only as good as its underlying assumptions, but the results it yields are reasonable and need not be taken with too large a grain of salt.

Operations Manual of Program Usage

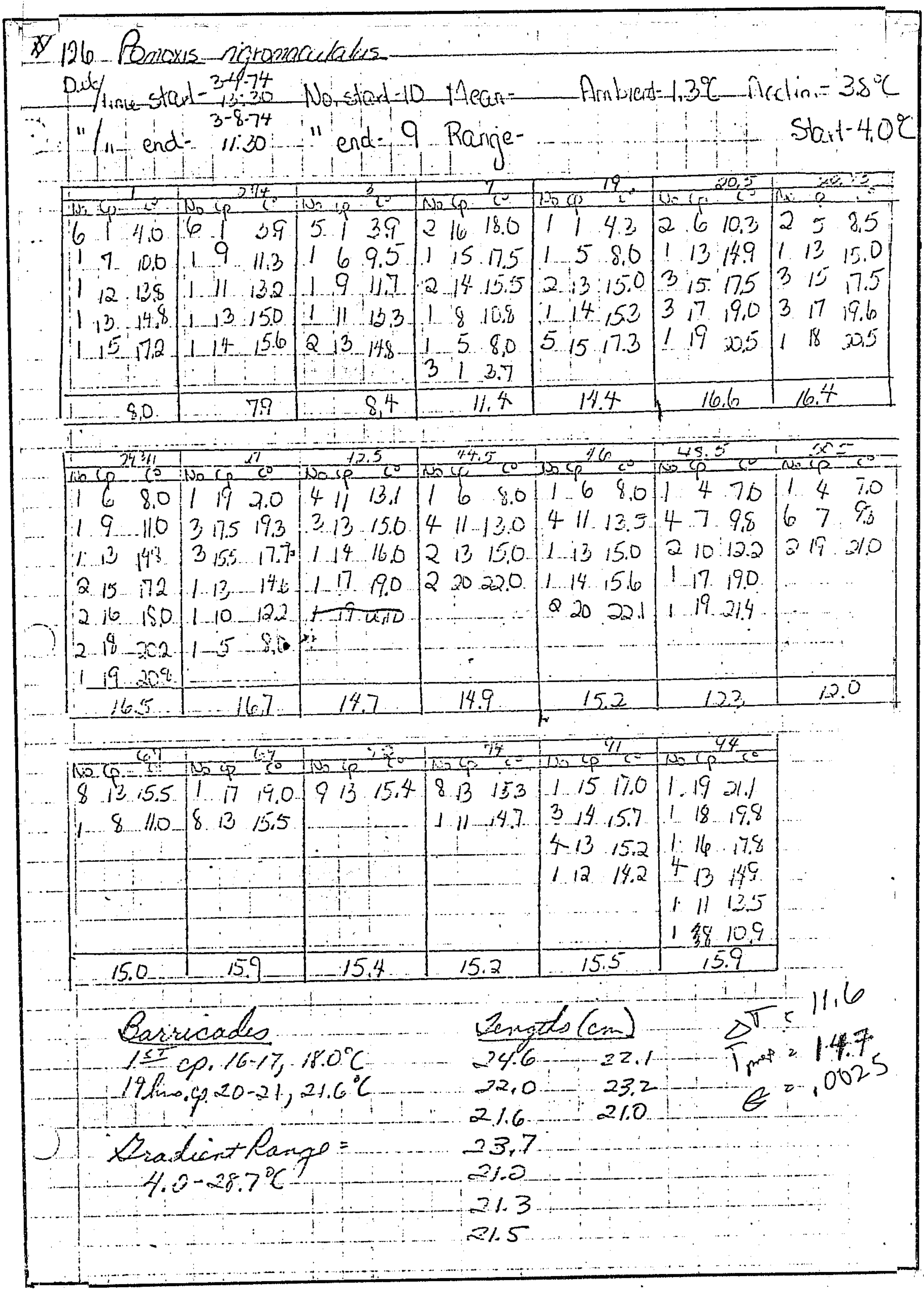
Part I. Program EXPO

The purpose of this program is to calculate the mean, standard deviation, and skewing factor for the distribution of an experimental group of fish in a thermal gradient. The program evaluates data such as is generated by Study II. It is designed for use in an interactive environment such as is provided by time-sharing.

A sample run is shown in figure 1. The program will prompt the user for the required data. Computer generated prompting and output is shown in upper-case letters. The first prompt is for the number of data points and total units. The number of data points refers to the total number of (temperature-number of fish) pairs to be evaluated (not to exceed 30). Total number of units is the total number of fish in the evaluation, or in other words, the sum of the second members of the data point pairs. This information is obtained from the Study II data, an example of which is shown in figure 2. Data used in the program should only be taken from steady state observations. In this case, steady state is defined to exist when the mean preferred temperature of the fish is appoximately equal to the final preferred temperature. In the example, the last nine observations have been chosen as satisfying this criterion. It is important to use as

```
LOAD EXPO
HOW MANY DATA POINTS AND TOTAL UNITS?
?
30 81
ENTER POSITION AND VALUE
?
8. 1 13.3 4 15. 1 15.6 1 22.1 2 7. 1 9.8 4 12.2 2 19. 1 21.4 1 7. 1 9.8 6
?
21. 2 15.5 8 11. 1 19. 1 15.5 8 15.4 9 15.3 8 14.7 1 17. 1 15.7 3 15.2 4 14.2 1
?
21.1 1 19.8 1 17.8 1 14.9 4 13.5 1 10.9 1
ORDER IS: A, B, RESIDUAL**2, ITERATIONS
-.419386514E-01 .378784239E-01 .560115613E-01            2
ORDER: MEAN, STD.DEV., B, R(B), R(B-.1), R(B+.1)
 14.6950     3.19912     .378784E-01 .560115E-01 .571642E-01 .567635E-01
HOW MANY DATA POINTS AND TOTAL UNITS?
?
```

Figure 1. Program EXPO example.



IV 126 Pomoxis nigromaculatus

Date/time start - 3-4-74 13:30 No. start - 10 Mean - Ambient - 1.3°C Acclim. = 3.8°C

" / " end - 3-8-74 11:30 " end - 9 Range - Start - 4.0°C

1	2¼	3	7	19	20.5	[illegible]
No Cp C°	No Cp C°	No Cp C°	No Cp C°	No Cp C°	No Cp C°	No Cp C°
6 1 4.0	6 1 3.9	5 1 3.9	2 16 18.0	1 1 4.2	2 6 10.3	2 5 8.5
1 7 10.0	1 9 11.3	1 6 9.5	1 15 17.5	1 5 8.0	1 13 14.9	1 13 15.0
1 12 12.8	1 11 13.2	1 9 11.7	2 14 15.5	2 13 15.0	3 15 17.5	3 15 17.5
1 13 14.8	1 13 15.0	1 11 13.3	1 8 10.8	1 14 15.2	3 17 19.0	3 17 19.6
1 15 17.2	1 14 15.6	2 13 14.8	1 5 8.0	5 15 17.3	1 19 20.5	1 18 20.5
			3 1 3.7			
8.0	7.9	8.4	11.4	14.4	16.6	16.4

24¾	27	42.5	44.5	46	48.5	50.5
No Cp C°	No Cp C°	No Cp C°	No Cp C°	No Cp C°	No Cp C°	No Cp C°
1 6 8.0	1 19 21.0	4 11 13.1	1 6 8.0	1 6 8.0	1 4 7.0	1 4 7.0
1 9 11.0	3 17.5 19.3	3 13 15.0	4 11 13.0	4 11 13.5	4 7 9.8	6 7 9.8
1 13 14.3	3 15.5 17.7	1 14 16.0	2 13 15.0	1 13 15.0	2 10 12.2	2 19 21.0
2 15 17.2	1 13 14.6	1 17 19.0	2 20 22.0	1 14 15.6	1 17 19.0	
2 16 18.0	1 10 12.2	~~1 19 dead~~		2 20 22.1	1 19 21.4	
2 18 20.2	1 5 8.0					
1 19 20.9						
16.5	16.7	14.7	14.9	15.2	12.3	12.0

67	69	[illegible]	74	91	94
No Cp C°	No Cp C°	No Cp C°	No Cp C°	No Cp C°	No Cp C°
8 13 15.5	1 17 19.0	9 13 15.4	8 13 15.3	1 15 17.0	1 19 21.1
1 8 11.0	8 13 15.5		1 11 14.7	3 14 15.7	1 18 19.8
				4 13 15.2	1 16 17.8
				1 12 14.2	4 13 14.9
					1 11 12.5
					1 38 10.9
15.0	15.9	15.4	15.2	15.5	15.9

Barricades
1st cp. 16-17, 18.0°C
19 hrs. cp. 20-21, 21.6°C

Gradient Range =
4.0-28.7°C

Lengths (cm)

24.6	22.1
22.0	23.2
21.6	21.0
23.7	
21.0	
21.3	
21.5	

ΔT = 11.6
T_{pref} = 14.7
σ = .0025

Figure 2. Sample Data Sheet from Study II.

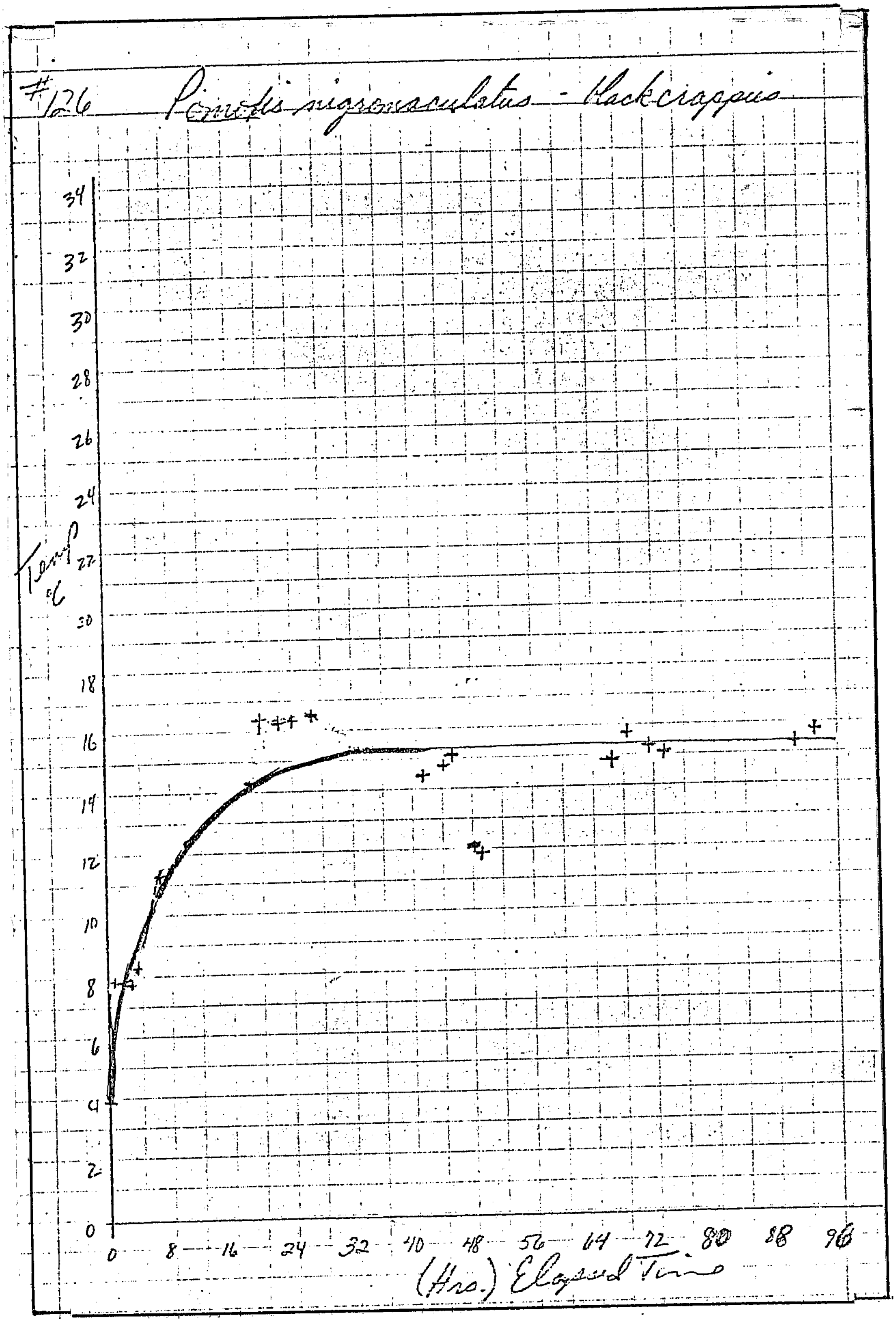


Figure 3. Sample Data Sheet from Study II.

many observations as possible since the reliability of the statistics depends on the total number of units. For small samples, pooling of observations will serve to approximate observations of large samples. Returning to figure 1, it can now be seen that the user-entered 30 refers to the thirty data pairs of the last nine observations, and the 81 refers to the sum of the fish observed at the various temperatures of the nine observations. These values are entered without decimal point and with one or more spaces between the two numbers. A carriage return completes the entry.

The next prompt requests the entry of the observation data pairs. Position refers to the temperature (thermal position) in °C, and value refers to the number of fish observed at that temperature. Values are entered leaving at least one space after each number. Input may be continued on as many lines as necessary. The tic marks shown on the example in figure 1 were penciled in by the user to facilitate bookkeeping. When the last values have been entered, the program begins calculation of the statistical descriptors. Four lines of output are generated, two descriptor lines and two lines of numbers.

In the first pair of lines, the number referred to as A has no significance to the general user and should be ignored. The second number, B, is the skewing factor. E followed by a signed number is powers of ten scientific notation. It is suggested that

B be rounded to no more than four significant figures in subsequent use. RESIDUAL**2 is the sum of the differences between the entered data and calculated distribution squared. Since this program uses a least squares fit to the data, this number should be much less than 1. If it is not small, extremal data pairs should be eliminated and the program re-run. Some practice with the program will assist the user in deciding when a re-run is necessary and which points to eliminate. ITERATIONS refers to the number of loops made in the program before the minimum residual was obtained. If this number is greater than approximately fifty, re-run as above since the program had difficulty fitting the probability function to the entered data.

In the next pair of lines of output one finds first the mean thermal position of the data entered. This value should agree closely with the means of the individual observation periods. If this value does not give good agreement, it should be re-run as above. The next value, STD.DEV., is the standard deviation $\underline{\sigma}$ of the entered distribution. This value should also be rounded to four significant figures for later use. B, the skewing factor, is repeated again in this line for convenience in recording. R (B), R (B - .1) and R (B + .1) are residual values and are further checks on the fit. R (B) should be less than the remaining two values. If it is not, a true least squares fit has not been achieved, and the program should be re-run as above. The program will begin prompting for the next run immediately after the last line of results is printed. To terminate the program, use the "BREAK" or "ATTN" key on the terminal.

Part II. Program FISHES

The purpose of this program is to describe the time dependent behavior of a species of fish exposed to a thermal plume. The output gives the probability of a fish occupying a particular point in space as a function of time. In addition, the steady state distribution, enhancement ratios and steady state rates of the final stable distribution are given. Data used by this program includes the statistics characteristic of a particular species at a particular season as generated by program EXPO, as well as site condition parameters such as outfall temperature and velocity.

A sample run is shown on pages 39 through 44. As in program EXPO, the user is prompted for the proper data inputs. The names of the requested data correspond directly with variable names in the program and are generally mnemonic for the quantities they represent.

i) Data entry

In entering requested data, numbers corresponding to names beginning with the letters I through N must be entered without decimal point. All other information may be entered with or without decimal point as desired. In the example, the first prompt requests the entry of values for the variables NOFISH, TLAKE, TPREF, EPIS, SKEW, STD. NOFISH (Number Of FISH) begins with the letter N. Thus it must be entered without decimal point. TLAKE (Temperature of LAKE) refers to the lake temperature of the simulated situation. TPREF (Temperature PREFerence) refers to the final preferred temperature of the species to be simulated. This value should correspond to the lake temperature condition selected, that is, if the lake temperature given is characteristic of winter conditions, the winter preferred temperature of the species should be used. This holds true for all variables related to the species to be simulated. TPREF is taken as the mean value generated by program EXPO. EPIS is the value of the rate of change of mean thermal position with time. It is determined in the following manner. In figure 3 is plotted the mean thermal position of the population as a function of elapsed time. A smooth curve as shown in the figure is drawn between the points, but not necessarily fitting any of the points exactly. A point (or points) is selected on the curve and the corresponding time and temperature noted for the point. EPIS is then calculated by:

$$\text{EPIS} = \left[-\ln\left(\frac{\Delta T}{\Delta T_0}\right)\right] \Big/ (t - t_0)$$

where: ΔT = (final preferred temperature - mean temperature at time t)

T_0 = (final preferred temperature - initial temperature at t_0)

t_0 = start time of run

t = time corresponding to selected point

$(t - t_0)$ = elapsed time in minutes

ln = natural logarithm

It is recommended that several points be chosen and the average value taken. This tends to offset the error in the freehand curve. Note: EPIS must be obtained from a run in which no artificial barriers to fish motion were present at any time and in which the fish did not congregate at one end of the gradient. Either condition would cause the value of EPIS to be indeterminate. EPIS can only be obtained from a run in which the fish had free access to all temperatures in the gradient and one in which the preferred temperature was sufficiently distant from the end of the gradient to minimize end effects on the distribution. SKEW (SKEWing factor) is the B value from program EXPO. STD (STandard Deviation) is the std.dev. value from EXPO.

Each value of a variable requested by the program should be separated from the previous value by at least one blank space as shown. A carriage return after the last variable of a line of input completes the input and signals the computer to proceed to the next step.

of 500 be chosen for the following reason. Each cycle of the program introduces a fish to the gradient. The first fish appears in compartment one at time zero, the next in compartment two, and so forth, repeating every 500 fish. This method, as opposed to starting all the fish in compartment 500 and letting them swim upgradient, was chosen to simulate entrainment effects as well as free selection response. This method probably overestimates entrainment, but the large number of fish introduced in the entraining region creates a distinct peak in the distribution, separate from the peak for fish beginning at or near lake conditions. This allows the user to observe differences in the two subpopulations until such time as the two peaks eventually merge. Five hundred or one thousand fish generally give sufficient detail for most purposes.

With these values of RUNTIM and NOFISH, a run can be made and detailed output generated. In this manner, the user can observe the most rapid changes in distribution and obtain final steady state conditions at minimal cost. The method is illustrated in the example given.

On the basis of this output, the user can decide if longer simulation periods would be desirable and can determine more efficiently the simulation period and number of fish which would give the desired information.

The next prompt requests values for the variables RUNTIM, TOUT, DTEMP, OMEGA, BETA, COUT, XFAL. RUNTIM (RUN TIMe) is the number of minutes to be simulated by the program from the time the fish are initially introduced to the plume until the simulation ends. TOUT (Temperature of the OUTfall) is the temperature in °C of the water leaving the exit. DTEMP, OMEGA and BETA are used to describe the plume resulting from a turbulent, oscillating jet. DTEMP (Delta TEMPerature) is the maximum temperature variation near the exit. Green, *et al*. (1972) found this temperature difference to be approximately 2-3°C for the Point Beach thermal plume. This may probably be considered a characteristic value for most plumes. OMEGA is the base rate of temperature fluction; from data of Green, *et al*. (1972) it seems to be $\sim(2\pi/.3$ min.), or 20. In other words, one complete cycle (2π) is completed in 1/3 minute. BETA describes the expansion or contraction of the distance between successive temperature crests. If BETA is negative, the distance expands so that the crests are closest together near the exit, and become further apart as distance increases along the plume centerline. If BETA is positive the reverse condition holds. A BETA of zero gives a linear function where crests occur every $4\pi^2$ meters along the centerline. In real plume conditions, the crests increase slightly in spacing with distance (BETA negative). (fig. 4) The initial spacing may differ slightly from $4\pi^2$ meters, but the difference is not significant to the model. A BETA of −.01 is suggested. Setting the values of DTEMP, OMEGA, BETA equal to zero gives a smooth decay of temperature with distance. In most cases this is the option of choice. The intrepid user may wish to experiment with these parameters to observe their influence on time dependent behavior of the fish population. It should be noted that if non-zero values of these parameters are used, the steady state distributions and enhancement ratios obtained by direct calculation are invalid for the conditions; however, the occupation probability tables (position tables) are still accurate.

COUT (Current at the OUTfall) is the speed of the plume current in meters per minute at the exit. XFAL (eXponential FALl-off rate) is the exponential rate of decay with distance of both temperature and velocity. From data presented in Paddock, et al. (1973) a value of ~.0025/meter is calculated. This value seems relatively independent of site conditions so long as the plume is turbulent.

The last prompt of the data input section requests VS, DLTFTR, and BOXLEN VS (Velocity of Swimming) is the maximum sustained cruising speed in meters per minute of the species of interest. Values for this variable can be found in the literature, measured in the laboratory by the methods of Brett, et al.

(1958), or estimated from the relationships between preferred temperature, metabolic activity, and cruising speed. A very approximate relation which might be used for this purpose is:

$$VS = 108 \cdot 10^{-(TPREF-10)/15} \text{meters/minute}$$

This relation was derived from data presented by Brett, et al. (1958) updated by more recent information, and from information given in graphic form in Fry (1967.) This relation should be used only as a last resort when no other information is available. In actual situations, the swimming speed varies with adaptation. However, in most cases, over the range of temperatures considered, the variation is less than ten percent. Variations due to size of fish and reliability of estimate (if used) create larger errors than the thermal adaptation variation, thus until better data creates a requirement for a better model, a constant maximum swimming speed is a good and reasonable assumption.

The next variable, DLTFTR (DeLta Time FacToR) is used to examine the effect if any, of variations in the time interval between transitions on the population. Normally, the time interval is calculated by the program so that there is a large probability of one transition in the time Δt, and a small probability of two or more transitions in that period. A value between zero and one decreases the transition probability and increases the probability that the simulated fish will remain at a particular location during the time interval. Values greater than one increase the two step transition probability and are not recommended. Persons experienced in Monte-Carlo simulation may use this parameter to good effect. Other users should use a value of one for this variable. Further information on the Monte-Carlo simulation process and the role of the time increment may be found in appendix III.

The final variable BOXLEN (<u>BOX</u> <u>LEN</u>gth) is the unit distance in meters of distance along the centerline. In the simulation, centerline distance is divided into 500 compartments or "boxes", each compartment being BOXLEN meters long. Fish travel from one box to the next in the time interval $\underline{\Delta t}$. The value of this variable should be chosen large enough so that conditions in box 500 are approximately the same as lake conditions, but yet small enough so that resolution is not lost. Values ranging from six to ten work well and are recommended.

After all data has been entered, the program will print "PROGRAM EXECUTING." This is to inform the user that all data has been accepted and that the simulated fish are merrily scampering through their simulated environment.

ii) Control and interpretation of output

The first indication that the computer has completed its deliberations is when it asks if the user wishes the position tables. The question should be answered with a simple yes or no. If the user enters no, the program will return three pieces of information, the number of iterations, the internal preferred temperature and the time to steady state rates. The number of iterations is a measure of the time required by the computer to perform the simulation. It may be estimated by:

$$\text{Iterations} = \frac{(\text{RUNTIM} \cdot \text{NOFISH} \cdot \text{VS})}{\text{DLTFTR} \cdot \text{BOXLEN}}$$

This is significant in estimation of costs for program use. For example, on the IBM 370/165 the program will perform about 400 iterations per second of execution time. To run 1000 fish for 1000 minutes with VS equal to 6m/min, BOXLEN equal to 6, and DLTFTR equal to one would take about 1 million iterations. At 400 iterations per second, that is 5000 seconds execution time or about 45 minutes. Multiplication of the time by the dollar rate for computer use provides an estimate of cost per run.

The second piece of information, the internal preferred temperature is an estimate of the temperature the average fish would prefer after RUNTIM minutes for the conditions in the plume. This may or may not be the same as the final preferred temperature and depends mainly on the position of the critical velocity point. The value printed should be rounded to one digit to the right of the decimal point. The internal preference is allowed to rise until the final preference is reached or until a fish, swimming at the maximum rate for its internal preference, becomes limited in motion to warmer waters by the current of the critical velocity point.

"Time to steady state reates" indicates the time it would take the average fish to adapt to plume conditions. A time greater than or equal to RUNTIM indicates that the fish either have not had time to adapt, or did not have a chance to adapt due to current or preferred temperature influences. This time is not the time to a steady state distribution. Under most conditions, a steady state distribution will not be achieved until a period ~100 times this period has elapsed. The value given for this time should be rounded to a last significant figure in the ten's place (Example: 142.67720 → 140).

If the user decides the position tables are desired, "yes" should be entered in response to the question of several paragraphs previous. The user is then asked to enter the number of the first position table to be printed. A number from one to ten, without decimal point, should be entered. The user determines the number to be entered in the following manner. During execution of the program, RUNTIM is divided into ten equal intervals. After each interval of simulated time has elapsed, the position of the fish is recorded. The user then decides the time at which the results become interesting and enters the number for the appropriate interval. For example, if a RUNTIM of 1000 is selected and the user decides that information on distributions previous to 600 minutes is uninteresting, a value of 6 should be entered. The table itself consists of 500 entries, twenty to a line, of the fraction of the total number of fish simulated (NOFISH) found occupying a particular compartment at the time of observation. Compartment 1 is at the upper left and represents the conditions at the outlet. Compartment 500, found at lower right, represents conditions 500 X BOXLEN meters out along the centerline. The table is compressed and each entry consists of a decimal point followed by one to three digits giving the fraction of total fish in that box.

After the last table is printed the number of iterations, internal preferred temperature, and time to steady state rates are given as described above.

At some point the user will be asked if he wishes to continue. If "yes" is entered, the user will be asked to supply a new RUNTIM, DLTFTR, NOFISH, AND BOXLEN. Values of all other variables will remain as initially entered. If "no" is entered, the user will be asked if the temperature table is desired. This table gives the temperature of the water in ^{o}C in each compartment. Entries correspond to entries in the position tables and consist of one or two digits to the left of the decimal point and one to the right. A simple yes or no is entered as desired.

The user will then be asked if the final rates are desired. If non-zero values of DTEMP, OMEGA and BETA have been entered previously in the run, "no" should be entered since the entries in the table will be meaningless as mentioned above. If "yes" is entered, a series of numbers will be printed for LOC, TEMP, CURRENT, LAMDA, MU and LAMDA-MU. LOC (LOCation) refers to the number of the compartment. TEMP is the water temperature in that compartment in ^{o}C and CURRENT is the current speed in meters per minute at that location. LAMDA is the rate in meters per minute that a fish can travel upstream to warmer water from that location. MU is the corresponding rate of travel downstream. The peak in the steady state distribution will occur where LAMDA-MU is zero, that is, where the sign changes from negative to positive. The printout begins at the location just above the critical velocity point and continues every five boxes after that. Since in the steady state no fish will be found above the critical velocity point, conditions for those compartments are considered uninteresting and are not listed.

Finally, the user will be asked if the steady state probabilities and enhancement ratios are desired. Again, if DTEMP, OMEGA, and BETA are non-zero, "no" should be entered for reasons given above. If "yes" is entered, a printout of LOCATION, PROBABILITY, and ENHANCEMENT RATIO will begin. The list starts just below the critical velocity point and continues every fifth compartment. Enhancement ratio is the ratio of fish density at the location to fish density in the lake. Probability is the probability that, given there is a fish somewhere between the critical velocity point and box 500, it will be found at that location. Due to the manner in which probability and enhancement ratio are calculated, only the first two significant figures should be considered reliable. This is a result of using a discrete state machine (digital computer) to perform the calculations and would require more effort to rectify than the accuracy of the input data could justify.

iii) Strategy of use

All attempts have been made to make this program as computationally efficient as possible. It is still possible, though, to use large blocks of computer time while gaining only minimal amounts of information. An optimum strategy has been formulated to permit the user to obtain maximum information at minimum cost.

First, it must be noted that there are two variables which have major influence on the time required by the program. These variables, RUNTIM and NOFISH can be manipulated to advantage by the user. It is thus suggested that NOFISH be initially set to one. Several runs of the program can then be made using different values of RUNTIM. An initial value of 500 for RUNTIM seems to work well. RUNTIM can be increased until the time to steady state rates is less than RUNTIM, or until the internal preferred temperature is approximately equal to the final preferred temperature. If the internal preference is approximately equal to the final preference it means the time to steady state is very large, and that a smaller RUNTIM can be selected to illustrate the more significant aspects of changes in distribution with time. If the time to steady state rates is less than RUNTIM, a new value of RUNTIM can be selected which is just slightly greater than the time to steady state rates. This procedure serves to determine an approximate limit for the time in which the most rapid changes in distribution occur. After the time to steady state rates has elapsed, changes in distribution occur very slowly and long runtimes are necessary to give significant changes in the distribution.

Once this value of RUNTIM has been selected, a new value of NOFISH must be chosen. It is recommended that some multiple

SAMPLE RUN OF PROGRAM FISHES

```
C AMBLOPLITES RUPESTRIS 1/15
READY
LOAD FISHES
ENTER:NOFISH,TLAKE,TPREF,EPIS,SKEW,STD
?
1 .8 25.3 .0023 -.0295 2.513
ENTER:RUNTIM,TOUT,DTEMP,OMEGA,BETA,COUT,XFAL
?
500 7.5 0. 0. 0. 122.5 .0025
ENTER:VS,DLTFTR,BOXLEN
?
5.9 1. 6.
PROGRAM EXECUTING
DO YOU WANT THE POSITION TABLES?
NO
TOTAL NUMBER OF ITERATIONS=        472
INTERNAL PREFERED TEMPERATURE= 7.6539001
TIME TO STEADY STATE RATES= 142.67720


DO YOU WISH TO CONTINUE?
YES
ENTER RUNTIM,DLTFTR,NOFISH,BOXLEN
?
200 1. 1000 6.
PROGRAM EXECUTING
DO YOU WANT THE POSITION TABLES?
YES
ENTER THE NUMBER OF THE FIRST POSITION TABLE TO BE PRINTED (1 TO 10)
?
6

OBSERVATION TIME=  120.00000.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .005.012.032.050.035.028.026.014.012.012.018.020.008
.012.010.008.010.014.004.012.010.004.008.010.008.004.002.008.010.004.004.006.008
.010.008.004.006.004.010.004.006.012.002.0  .010.008.008.008.006.006.008.004.006
.004.0  .002.004.002.002.0  .002.004.002.002.002.004.002.0  .002.002.004.002.002
.0  .002.006.002.0  .002.002.002.002.002.004.002.002.0  .004.002.002.004.0  .004
.004.002.002.002.0  .002.0  .004.004.002.002.002.002.002.002.002.002.004.002.0
.0  .004.004.002.002.002.002.0  .002.004.004.002.002.004.002.0  .0  .006.004.0
.0  .004.004.0  .002.004.002.004.002.002.002.004.004.002.002.002.002.0  .002.002
.002.002.004.004.002.002.002.002.002.004.002.002.004.002.004.004.0  .004.002.004
.004.002.004.004.002.0  .002.004.002.002.002.002.002.002.002.002.004.0  .0  .004
.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002
.002.002.002.002.004.0  .0  .004.002.002.002.002.002.002.002.002.002.002.002.002
.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002
```

(Continues)

SAMPLE RUN OF PROGRAM FISHES (CON'T.)

```
OBSERVATION TIME=  140.00000
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0   0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .004.012.028.050.038.020.020.022.024.014
.014.016.014.008.012.008.002.012.016.004.012.010.008.004.010.006.006.008.006.006
.004.002.010.010.010.004.006.010.004.006.008.006.004.004.006.014.004.008.008.004
.010.0  .004.004.002.004.0  .002.004.002.002.004.002.002.002.002.002.0  .004.002
.002.002.004.002.0  .004.002.0  .002.004.002.002.002.002.004.004.002.0  .0  .002
.002.004.002.004.002.002.0  .004.004.002.002.002.002.002.002.002.004.0  .002.002
.004.002.0  .004.002.002.002.0  .004.002.004.002.002.002.002.002.002.004.004.0
.0  .002.004.002.002.004.002.004.002.002.002.004.004.002.002.002.002.0  .002.002
.002.002.004.004.002.002.002.002.002.002.002.006.004.0  .004.002.002.004.002.004
.004.004.002.002.002.004.002.002.002.002.002.002.002.002.002.002.002.002.002.002
.002.002.002.002.002.002.002.002.002.002.0  .004.002.002.004.002.0  .0  .002.004
.002.002.004.002.0  .0  .002.004.002.0  .002.002.002.002.002.002.002.002.002.002
.002.002.002.002.002.002.002.002.002.002.002.002.004.002.002.002.002.002.004.0

OBSERVATION TIME=  160.00000
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .003.011.035.040.043.030.026
.018.008.018.018.016.010.014.008.010.004.010.014.004.008.012.010.004.014.006.008
.012.004.006.010.014.004.008.012.002.006.008.004.008.002.008.014.008.002.006.006
.010.0  .004.004.0  .004.002.002.002.002.004.004.002.002.0  .002.002.002.004.002
.002.002.004.002.0  .004.002.0  .002.004.002.002.004.0  .002.004.002.002.0  .002
.002.002.004.004.002.002.002.004.002.0  .004.002.002.002.002.002.002.002.002.002
.0  .004.004.002.002.002.002.0  .004.004.004.0  .002.002.002.004.0  .004.004.0
.0  .002.004.004.002.004.002.0  .002.004.002.004.004.002.002.0  .002.002.002.002
.002.002.004.004.002.0  .004.004.002.0  .002.004.004.004.004.0  .0  .006.002.004
.004.002.006.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.004.002
.0  .002.0  .002.004.002.002.002.002.0  .002.004.004.002.0  .002.002.0  .002.004
.004.002.0  .002.002.0  .002.004.004.0  .002.002.002.002.002.002.002.002.002.002
.002.002.0  .004.002.002.002.002.002.002.002.002.002.002.002.002.002.002.004.0
```

(Continues)

SAMPLE RUN OF PROGRAM FISHES (CON'T.)

```
OBSERVATION TIME=  180.00000
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .002.018.035.043
.032.024.030.022.010.018.020.012.010.014.008.010.004.014.010.002.018.012.012.014
.014.012.004.010.012.010.002.012.006.004.006.008.004.002.004.020.004.006.008.006
.010.002.002.002.0  .004.002.002.002.002.004.004.002.002.0  .002.004.002.0  .004
.002.004.002.002.0  .004.002.0  .002.002.002.004.0  .004.004.002.002.002.0  .002
.0  .004.004.006.0  .002.002.004.002.002.002.002.002.002.004.0  .002.002.002.004
.0  .004.002.002.002.002.002.0  .002.004.004.004.004.0  .002.0  .002.004.004.0
.0  .002.004.004.004.0  .002.002.002.006.002.002.006.002.002.002.002.002.002.002
.004.004.0  .0  .002.0  .004.002.002.004.002.002.004.002.004.004.0  .002.002.008
.004.004.002.002.002.002.002.002.002.002.002.002.002.002.002.002.004.002.0  .002
.002.0  .004.004.0  .002.002.002.002.0  .004.004.0  .002.002.002.002.0  .004.004
.0  .002.002.002.002.0  .004.004.0  .0  .002.002.002.002.002.004.002.002.002.002
.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.004.0

OBSERVATION TIME=  200.00000
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0
.0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .0  .006
.013.036.051.028.020.032.028.006.016.022.012.010.010.010.010.012.012.010.018.016
.026.018.010.006.008.008.004.010.006.004.010.004.006.008.002.014.010.0  .010.004
.010.002.002.004.0  .004.002.002.004.002.002.004.002.004.0  .0  .002.004.002.002
.0  .004.004.002.0  .004.002.002.002.0  .002.004.002.002.004.002.002.004.0  .004
.004.002.0  .002.002.002.0  .004.004.002.002.002.002.002.002.002.002.004.002.0
.002.004.002.002.002.002.002.002.002.002.004.002.002.004.002.0  .002.004.004.0
.0  .004.002.002.004.002.002.004.002.002.002.002.002.004.002.002.002.002.002.002
.002.002.006.004.0  .0  .004.002.002.004.002.002.004.002.004.002.002.004.004.004
.004.004.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002
.004.0  .0  .004.002.002.002.002.004.0  .0  .004.002.002.002.002.004.0  .0  .004
.002.002.002.002.004.0  .0  .004.002.002.002.002.002.002.002.002.002.002.002.002
.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.002.004.0
TOTAL NUMBER OF ITERATIONS=    158110
INTERNAL PREFERED TEMPERATURE= 7.6373749
TIME TO STEADY STATE RATES= 142.27031
```

(Continues)

SAMPLE RUN OF PROGRAM FISHES (CON'T.)

```
DO YOU WISH TO CONTINUE?
NO
DO YOU WANT THE TEMPERATURE TABLE?
YES
 7.4 7.3 7.2 7.1 7.0 6.9 6.8 6.7 6.7 6.6 6.5 6.4 6.3 6.2 6.2 6.1 6.0 5.9 5.8 5.8
 5.7 5.6 5.5 5.5 5.4 5.3 5.3 5.2 5.1 5.1 5.0 4.9 4.9 4.8 4.8 4.7 4.6 4.6 4.5 4.5
 4.4 4.4 4.3 4.3 4.2 4.2 4.1 4.1 4.0 4.0 3.9 3.9 3.8 3.8 3.7 3.7 3.6 3.6 3.6 3.5
 3.5 3.4 3.4 3.4 3.3 3.3 3.3 3.2 3.2 3.1 3.1 3.1 3.0 3.0 3.0 2.9 2.9 2.9 2.8 2.8
 2.8 2.8 2.7 2.7 2.7 2.6 2.6 2.6 2.6 2.5 2.5 2.5 2.5 2.4 2.4 2.4 2.4 2.3 2.3 2.3
 2.3 2.3 2.2 2.2 2.2 2.2 2.1 2.1 2.1 2.1 2.1 2.0 2.0 2.0 2.0 2.0 2.0 1.9 1.9 1.9
 1.9 1.9 1.9 1.8 1.8 1.8 1.8 1.8 1.8 1.8 1.7 1.7 1.7 1.7 1.7 1.7 1.7 1.6 1.6 1.6
 1.6 1.6 1.6 1.6 1.6 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.5 1.4 1.4 1.4 1.4 1.4
 1.4 1.4 1.4 1.4 1.4 1.4 1.3 1.3 1.3 1.3 1.3 1.3 1.3 1.3 1.3 1.3 1.3 1.3 1.3 1.3
 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.2 1.1 1.1 1.1 1.1
 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.1 1.0
 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0
 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 0.9 0.9 0.9 0.9 0.9 0.9 0.9
 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9
 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9
 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9 0.9
 0.9 0.9 0.9 0.9 0.9 0.9 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8 0.8
```

(Continues)

SAMPLE RUN OF PROGRAM FISHES (CON'T.)

```
DO YOU WANT THE FINAL RATES?
YES
 LOC   TEMP     CURRENT         LAMDA           MU              LAMDA-MU
  202   1.124    5.9186726      -.15894604       6.0589485      -6.2178946
  207   1.100    5.4910059       .23136997       5.6684475      -5.4370775
  212   1.079    5.0942459       .58425617       5.3155432      -4.7312870
  217   1.058    4.7261543       .90169334       4.9980183      -4.0963249
  222   1.040    4.3846588      1.1856508        4.7141047      -3.5284538
  227   1.022    4.0678396      1.4383469        4.4613972      -3.0230503
  232   1.006    3.7739086      1.6615038        4.2381411      -2.5766373
  237   0.991    3.5012197      1.8575172        4.0422754      -2.1847582
  242   0.978    3.2482347      2.0286627        3.8712559      -1.8425932
  247   0.965    3.0135288      2.1770267        3.7229319      -1.5459051
  252   0.953    2.7957830      2.3047943        3.5950079      -1.2902136
  257   0.942    2.5937672      2.4141636        3.4856186      -1.0714550
  262   0.932    2.4063511      2.5072889        3.3924761      -.88518715
  267   0.922    2.2324762      2.5861778        3.3137493      -.72757149
  272   0.913    2.0711660      2.6524372        3.2474632      -.59502602
  277   0.905    1.9215117      2.7079554        3.1918497      -.48389435
  282   0.898    1.7826681      2.7542048        3.1456881      -.39148331
  287   0.890    1.6538591      2.7923813        3.1073351      -.31495380
  292   0.884    1.5343571      2.8240681        3.0757427      -.25167465
  297   0.878    1.4234905      2.8500776        3.0498466      -.19976902
  302   0.872    1.3206339      2.8713589        3.0285854      -.15722656
  307   0.867    1.2252083      2.8886452        3.0111656      -.12252045
  312   0.862    1.1366796      2.9026871        2.9971476      -.94460487E-01
  317   0.858    1.0545473      2.9140491        2.9857883      -.71739197E-01
  322   0.854     .97834998     2.9232359        2.9767208      -.53484917E-01
  327   0.850     .90765804     2.9305811        2.9694233      -.38842201E-01
  332   0.846     .84207302     2.9363823        2.9635305      -.27148247E-01
  337   0.843     .78122771     2.9410543        2.9589005      -.17846107E-01
  342   0.840     .72477925     2.9446068        2.9553308      -.10724068E-01
  347   0.837     .67240924     2.9474602        2.9524698      -.50096512E-02
  352   0.834     .62382364     2.9496346        2.9503031      -.66852570E-03
  357   0.832     .57874787     2.9513845        2.9486523       .27322769E-02
  362   0.829     .53692949     2.9526348        2.9473801       .52547455E-02
  367   0.827     .49813306     2.9534864        2.9464617       .70247650E-02
  372   0.825     .46213973     2.9541559        2.9458294       .83265305E-02
  377   0.823     .42874718     2.9546080        2.9453735       .92344284E-02
  382   0.822     .39776713     2.9549341        2.9450788       .98552704E-02
  387   0.820     .36902589     2.9550571        2.9449549       .10102272E-01
  392   0.819     .34236145     2.9550943        2.9448862       .10208130E-01
  397   0.817     .31762367     2.9549999        2.9448433       .10156631E-01
  402   0.816     .29467446     2.9550085        2.9450378       .99706650E-02
  407   0.815     .27338105     2.9549046        2.9451742       .97303391E-02
  412   0.814     .25362778     2.9547424        2.9452715       .94709396E-02
  417   0.813     .23530179     2.9545012        2.9454260       .90751648E-02
  422   0.812     .21829998     2.9542885        2.9456024       .86860657E-02
  427   0.811     .20252657     2.9540691        2.9458447       .82244873E-02
  432   0.810     .18789190     2.9539318        2.9461317       .78001022E-02
  437   0.810     .17431563     2.9537458        2.9463053       .74405670E-02
  442   0.809     .16172040     2.9535160        2.9464321       .70838928E-02
  447   0.808     .15003520     2.9533205        2.9466600       .66604614E-02
  452   0.808     .13919437     2.9531517        2.9469223       .62294006E-02
  457   0.807     .12913609     2.9529266        2.9470816       .58450699E-02
  462   0.807     .11980528     2.9527760        2.9473009       .54750443E-02
  467   0.806     .11114866     2.9525347        2.9473801       .51546097E-02
  472   0.806     .10311759     2.9523973        2.9475660       .48313141E-02
  477   0.805     .95666766E-01 2.9522657        2.9477377       .45280457E-02
  482   0.805     .88753819E-01 2.9521084        2.9479284       .41799545E-02
  487   0.805     .82340896E-01 2.9519663        2.9480963       .38700104E-02
  492   0.804     .76391280E-01 2.9517984        2.9481316       .36668777E-02
```

(Continues)

SAMPLE RUN OF PROGRAM FISHES (CON'T.)

```
DO YOU WANT THE STEADY STATE PROBABILITIES AND ENHANCEMENT RATIOS?
YES
 LOCATION    PROBABILITY        ENHANCEMENT RATIO
  207        .47436002E-30          .11300342E-27
  212        .15701581E-24          .37404768E-22
  217        .21403056E-20          .50986984E-18
  222        .41934351E-17          .99897245E-15
  227        .20375505E-14          .48539119E-12
  232        .33676458E-12          .80225035E-10
  237        .23385807E-10          .55710352E-08
  242        .79581319E-09          .18958093E-06
  247        .14953915E-07          .35623652E-05
  252        .17077605E-06          .40682775E-04
  257        .12828978E-05          .30561583E-03
  262        .67753044E-05          .16140320E-02
  267        .26610272E-04          .63391775E-02
  272        .81549777E-04          .19427028E-01
  277        .20311061E-03          .48385601E-01
  282        .42565167E-03          .10140002
  287        .77304663E-03          .18415743
  292        .12472433E-02          .29712194
  297        .18256030E-02          .43490046
  302        .24672796E-02          .58776253
  307        .31241968E-02          .74425524
  312        .37516954E-02          .89373976
  317        .43161996E-02          1.0282183
  322        .47964044E-02          1.1426134
  327        .51841736E-02          1.2349892
  332        .54805167E-02          1.3055849
  337        .56921616E-02          1.3560038
  342        .58304556E-02          1.3889484
  347        .59074052E-02          1.4072800
  352        .59348084E-02          1.4138079
  357        .59235655E-02          1.4111290
  362        .58834068E-02          1.4015627
  367        .58222450E-02          1.3869925
  372        .57463609E-02          1.3689156
  377        .56611411E-02          1.3486137
  382        .55701099E-02          1.3269281
  387        .54768398E-02          1.3047094
  392        .53831674E-02          1.2823944
  397        .52911900E-02          1.2604828
  402        .52014738E-02          1.2391109
  407        .51152147E-02          1.2185621
  412        .50329156E-02          1.1989565
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  427        .48116408E-02          1.1462431
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  437        .46852604E-02          1.1161366
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  447        .45752451E-02          1.0899286
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  457        .44796951E-02          1.0671663
  462        .44369437E-02          1.0569820
  467        .43972991E-02          1.0475378
  472        .43602847E-02          1.0387201
  477        .43260418E-02          1.0305624
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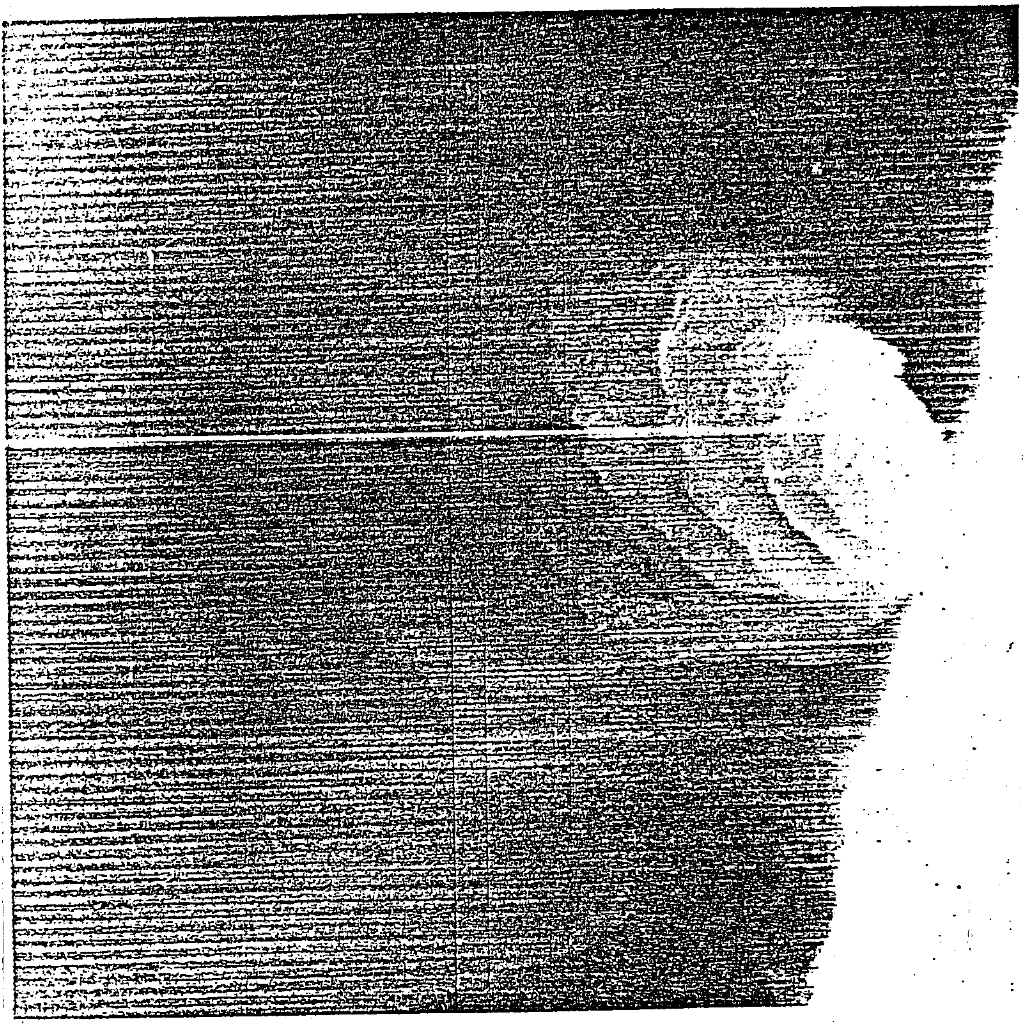

Figure 4. Thermal images of other thermal plumes: Sheboygan Edgewater Plant.

FINDINGS

The results of this study are presented in tables 1 through 4 of this section. The first table is a list of species divided into groups according to maximum enhancement ratio. The second table groups species according to location of maximum enhancement ratio. The third table groups the species according to time to steady state rates. Table 4 gives the parameters that were used in program FISHES to obtain the above information.

TABLE 1

ENHANCEMENT RATIO LEVELS

Maximum Enhancement Ratio	Tab actual ratios	Species and date
1.0 (Lake level)		*L. macrochirus* (2/20)
		N. hudsonius (3/2)
		P. nigromaculatus (4/23)
		P. annularis (5/6)
		P. annularis (7/5)
		L. gibbosus (7/18)
		P. nigromaculatus (10/9)
		P. flavescens (12/18)
1 - 10	1.4	*A. rupestris* (1/15)
	4.8	*I. nebulosus* (1/21)
	2.0	*L. gibbosus* (4/3)
	1.4	*I. nebulosus* (6/25)
	1.3	*N. flavus* (10/24)
10 - 120	91	*P. nigromaculatus* (2/8)
	10	*C. carpio* (3/22)
	120	*P. nigromaculatus* (12/7)
> 120	640	*N. atherinoides* (1/15)

TABLE 2

POSITION OF MAXIMUM ENHANCEMENT RATIO

Location of Maximum ER (meters from outlet)	Tab actual ratios	Species and date
lake (>3000)		*L. macrochirus* (2/20)
		N. hudsonius (3/2)
		P. nigromaculatus (4/23)
		P. annularis (5/6)
		P. annularis (7/5)
		L. gibbosus (7/18)
		P. nigromaculatus (10/9)
		P. flavescens (12/18)
2000 – 3000	2130	*A. rupestris* (1/15)
	2420	*I. nebulosus* (1/21)
	2210	*C. carpio* (3/22)
	2070	*L. gibbosus* (4/3)
	2480	*I. nebulosus* (6/25)
	2360	*N. flavus* (10/24)
1000 – 2000	1710	*N. atherinoides* (1/15)
	1840	*P. nigromaculatus* (2/8)
	1780	*P. nigromaculatus* (12/7)

TABLE 3

ADAPTATION TIME

Time to Steady-State Rates (minutes)	Species and date
> 3000	*N. hudsonius* (3/2)
	P. nigromaculatus (4/23)
	P. annularis (5/6)
	P. annularis (7/5)
	L. gibbosus (7/18)
	P. nigromaculatus (10/9)
500 – 3000	*P. nigromaculatus* (2/8)
	L. gibbosus (4/3)

TABLE 3 (CON'T.)

Time to Steady-State Rates (minutes)	Species and date	
100 - 500	A. rupestris	(1/15)
	N. atherinoides	(1/15)
	I. nebulosus	(1/21)
	L. macrochirus	(2/20)
	C. carpio	(3/22)
	N. flavus	(10/24)
	P. flavescens	(12/18)
< 100	I. nebulosus	(6/25)
	P. nigromaculatus	(12/7)

Figure 5 indicates the location of the maximum enhancement ratios as a function of distance from the outfall. Graphs of the expected steady state enhancement ratios for each species are presented in Appendix I.

TABLE 4

MODEL PARAMETERS OF STUDY II DATA

Species	Date	Acclimation Temperature (°C)	Preferred Temperature (°C)	Season	Standard Deviation (°C)	Skewing Factor	EPIS (l/min)	Swimming Speed (m/min)	Outlet Temperature (°C)
Ambloplites rupestris	1/15	0.8	25.3	W	2.513	-.0295	.0023	5.9 •	7.5
Notropis atherinoides	1/15	0.8	11.0	W	1.638	.0152	.003	6.8 •	7.5
Ictaluris nebulosis	1/21	1.0	12.2	W	1.616	-.5597	.00069	1.5 •	8.0
Pomoxis nigromaculatus	2/8	3.0	16.1	W	3.791	-.1035	.0012	5.1 •	9.5
Lepomis macrochirus	2/20	4.0	26.3	W	2.838	.2677	.0014	3.7	11.0
Notropis hudsonius	3/2	4.5	9.4	W	3.652	-.0429	.008	7.1 •	12.0
Cyprinus carpio	3/22	7.9	25.2	Sp	1.025	-.2188	.0010	2.4 •	16.0
Lepomis gibbosus	4/3	9.0	25.0	Sp	3.117	.0756	.0015	4.9	19.0
Pomoxis nigromaculatus	4/23	11.3	18.4	Sp	3.628	-.0312	.0015	5.4 •	20.5
Pomoxis annularis	5/16	13.1	15.8	Sp	7.442	.0277	.005	6.1 •	24.0
Ictaluris nebulosis	6/25	18.2	25.8	Su	1.204	.1348	.2 *	2.0 •	31.0
Pomoxis annularis	7/5	21.7	16.4	Su	2.790	-.0791	.01	5.9 •	31.5
Lepomis gibbosus	7/18	23.8	29.6	Su	4.283	.0617	.01 *	4.9	30.5
Pomoxis nigromaculatus	10/9	20.7	25.8	A	3.488	.2113	.0022	5.9 •	29.0
Noturis flavus	10/24	16.9	25.4	A	1.517	.0166	.0019	3.7 •	24.0
Pomoxis nigromaculatus	12/7	0.8	21.8	W	1.970	-.0952	.0035	5.9 •	10.5
Perca flavescens	12/18	0.3	19.6	W	7.092	-.0367	.008	7.3 •	8.5

* Suspect due to low sample density

• Estimated

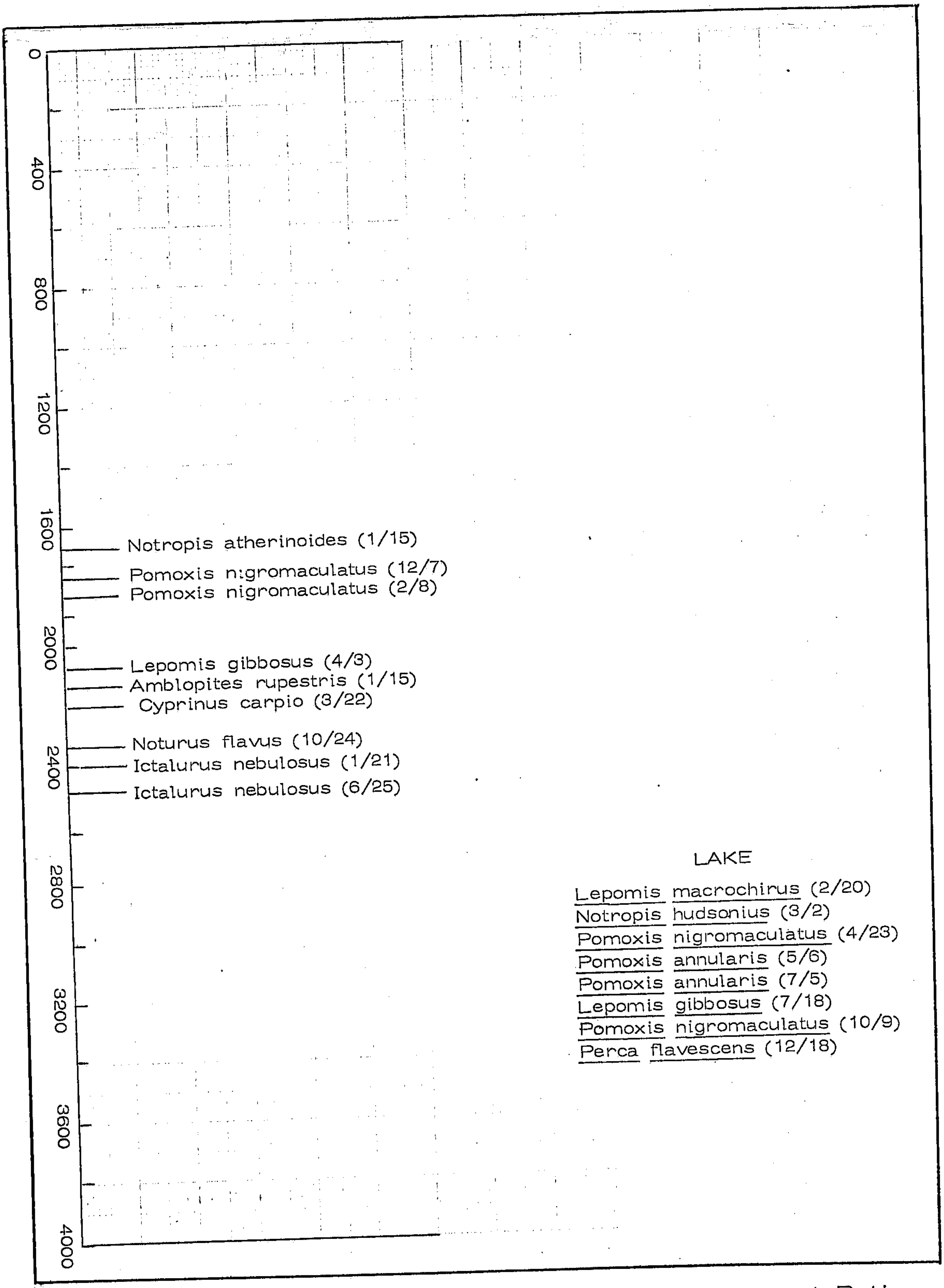

Figure 5. Graphic Position of Maximum Enhancement Ratio

ANALYSIS

This section will attempt to interpret and elaborate the data presented in the RESULTS section. Steady state and time dependent features of the results will be commented upon and related to the initial study objectives.

Steady state conditions projected by the model will be considered first. Examining the steady state enhancement ratios of table 1 in the results section, it is seen that the expected ratios are considerably less than those projected by the steady state model of Robb (1974). This is primarily due to the limitations on fish motion imposed by the induced current. The proposed exit velocity of 122.5 meters per minute (6.7 feet per second) is at least an order of magnitude greater than the maximum sustained swimming speed of any species of interest. Although decay of current velocity is exponential with distance from the exit, the current is still greater than swimming speed at centerline distances exceeding one kilometer. Since temperature follows the same decay pattern as velocity, the excess temperature (degrees above ambient) accessable to fish is less than one degree C for a proposed maximum excess temperature at the exit of 11°C. This small temperature excess generally provides little stimulus for fish to seek warmer waters against the not inconsiderable current that exists for some distance beyond the critical velocity point. (point where current equals maximum sustained swimming speed) The previous model did not take current effects into account and hence overestimated the excess temperatures available to the fish, and thus the maximum enhancement ratios possible.

Further examination of table 1 reveals an even more interesting feature. The low enhancement ratios (essentially no enhancement over lake conditions) occur during late spring, summer, and autumn when lake temperatures are warmest. The highest enhancement occurs during winter months when the temperature difference between preferred and ambient temperatures is greatest. Data for the one species for which there is full seasonal information, *Pomoxis nigromaculatus*, illustrates this seasonal variability in enhancement. During winter (2/8) a high ratio of ~90 is observed. This declines during spring to a value of lake level (4/23) and remains at this level through autumn (10/9) and then increases to a winter value of ~120 (12/7). Information from other species for which there is partial seasonal information (*Ictalurus nebulosus*, *Lepomis gibbosus*, *Pomoxis annularis*) bears out this trend.

Table 2 of the results further emphasizes the problem of high current velocity. The large distances shown are mainly a result of current since for no species listed is the critical velocity point less than one kilometer (centerline distance) from the exit.

Extension of distance to maximum enhancement ratio beyond the critical velocity point is due to temperature preference effects and illustrates the trade-off between the preference for warmer water and the disinclination of fish to expend extra energy fighting the current to reach the warmer waters. Again, seasonal effects may be noted. In the warm water seasons fish tend to remain further out near lake conditions. In winter, the fish tend to migrate in closer to warmer water.

The time to steady state rates given in table 3 of the results is useful in estimation of the time necessary to achieve a stable distribution after a plume is introduced to the environment. The times given do not indicate the time to steady state distribution directly, but rather indicate the time necessary to provide sufficient exposure for acclimation to the maximum available temperature. Additional time is required for the fish to swim about and try different conditions before settling on some preferred combination of temperature and current. This seeking behavior requires a period about 100 times greater than the acclimation time for the proposed conditions. Thus, time to a stable distribution is about 100 times the time to steady state rates given in the table. One item should be noted, and that is that the times in excess of 3000 minutes given in the table are generally misleading. These times generally occur for species where lake conditions are preferred. When the plume is introduced, these fish are already near their steady state distributions and no amount of time will alter the distribution significantly. Very large times coupled with maximum enhancement ratios of one should be ignored or considered to be close to zero. The time to steady state seems to be a function of both the difference between acclimation and preferred temperatures and the swimming speed. The temperature difference determines the strength of the thermal selection stimulus and the swimming speed is the implementation of the stimulus response.

Time dependent effects are numerous, but perhaps one of the most important is the response to entrainment. The problem here is that during entrainment, the fish may be subjected to temperatures considerably in excess of their critical thermal maximum. With the high exit velocity proposed, turbulence, and hence entrainment, is expected to be considerable. While it is not possible at present to estimate the fraction of the population affected by entrainment, it is possible to observe what happens to entrained fish. The model indicates that even in the worst possible case, that of fish entrained near the exit, the maximum exposure time of fish to temperatures in excess of five degrees above ambient is less than five minutes and exposure to one or more degrees above ambient is less than 30 minutes. For most species this is not sufficient exposure to cause death even if the outlet temperature is considerably in excess of ambient.

A further time dependent effect is that fish introduced initially to temperatures significantly in excess of ambient, as in entrainment, acclimate faster and tend to remain in water warmer than that selected by fish swimming up-gradient from lake conditions. The two subpopulations of entrained fish and lake fish eventually merge at steady state, but exhibit separate and distinct mean preferences until that time. This phenomenon has been observed in the laboratory, and also in the model.

RECOMMENDATIONS

This section covers two areas, the first pertaining to plant operation or fisheries management and the second to the model itself.

In the first area, if it is desired that the area fishery be augmented by using the warm water as an attractant, it is recommended that the exit velocity be considerably reduced, since this is the major limiting factor to fish accumulation. At this late date in the construction, such action, since it would require substantial modification of the discharge structure, is probably not practical. It should be taken into consideration, however, on any proposed or planned plants.

Although fish are attracted to the plume area during certain times of the year, this phenomenon cannot be relied upon as a rapid stocking mechanism. The tendency of the fish to accumulate in narrow bands makes the area particularly susceptable to overfishing, especially by commercial methods. Due to the time required to achieve steady state distributions, restocking of the area by migration could require several weeks. This could have repercussions in the area surrounding the plume as well as in the plume itself. It is recommended that careful attention be paid to commercial fishing in the actual region of the plume, especially in the areas beyond the 1° isotherm during periods of fish aggregation.

The possible directive effects of a warm water region are also not to be ignored. The possibility of alteration of spawning or migration cycles of fish exposed to the plume should be more fully investigated. It appears that the region affected by the plume will be considerably greater than that reported by Herdendorf (1972) and a considerably larger population may be affected than originally anticipated. It is suggested that the original estimates be reviewed with special attention to areas of regions beyond the 1° isotherm since greatest accumulations are projected for regions 0.1 to 1.0 degrees above ambient.

The model, while yielding intuitively reasonable results, is currently unverified. Primary emphasis should be given to determination of the accuracy of the model. For this purpose, it is not necessary to wait until the Davis-Besse plant begins operation. Projections can be made and compared to field data for river mouth studies or studies of currently existing plants discharging hot water into a lake environment.

Further refinement of the model is also recommended. Fortunately, the structure of the model facilitates modification except in cases where simultaneous observation of two or more species is desired. Provision for variable plant operation during the simulation period should be made. This would permit analysis of such occurences as a plant shut-down and allow estimation of subsequent cold-shock mortality. Provision for fish removal during the simulation period is also advisable. This would give information on the influence of various fishing strategies and fisheries management practices on the area populations. It is recommended that effort be devoted to improvement of the functions describing rates of fish movement, swimming speed, and other population parameters, preferably by replacement of the present deterministic expressions with probability functions obtained by actual field or laboratory observation.

Finally, extension of the model to a two dimensional case should be considered. This would involve replacement of the present functions for evaluation of temperature and current, and would considerably increase the computer time required, but would have the advantage of providing a more comprehensive picture of the areas affected by the plume as well as influences on the spatial distribution of the fish populations.

ADDENDUM

It has recently been brought to the attention of the author that the swimming speeds used in this study are ~1/4 those observed by most researchers. The speeds used are in agreement with those reported by Brett (1958) but should probably be modified in any subsequent use of the model. The equation for approximation of swimming speed from preferred temperature has been modified to reflect this increase.

An increase in swimming speed is not expected to cause any significant changes in the qualitative aspects of the results. The critical velocity point will be decreased by ~500 meters and the corresponding maximum available temperature increased by 3-4°C. The maximum enhancement ratios for fish exhibiting accumulations in the plume region are expected to increase somewhat, but should change little otherwise.

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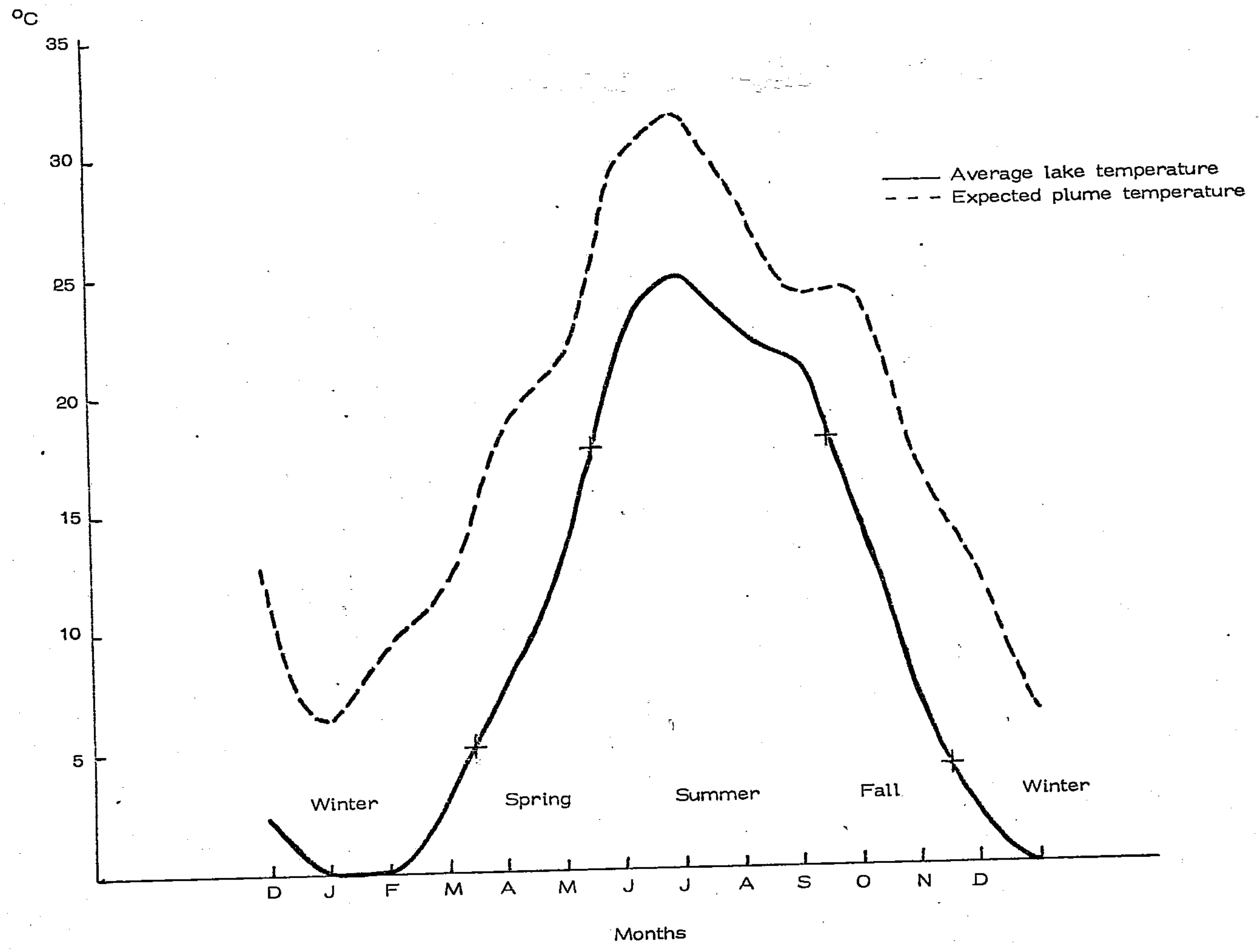
APPENDIX I

EXPECTED STEADY STATE DISTRIBUTIONS FOR THE SPECIES EXAMINED



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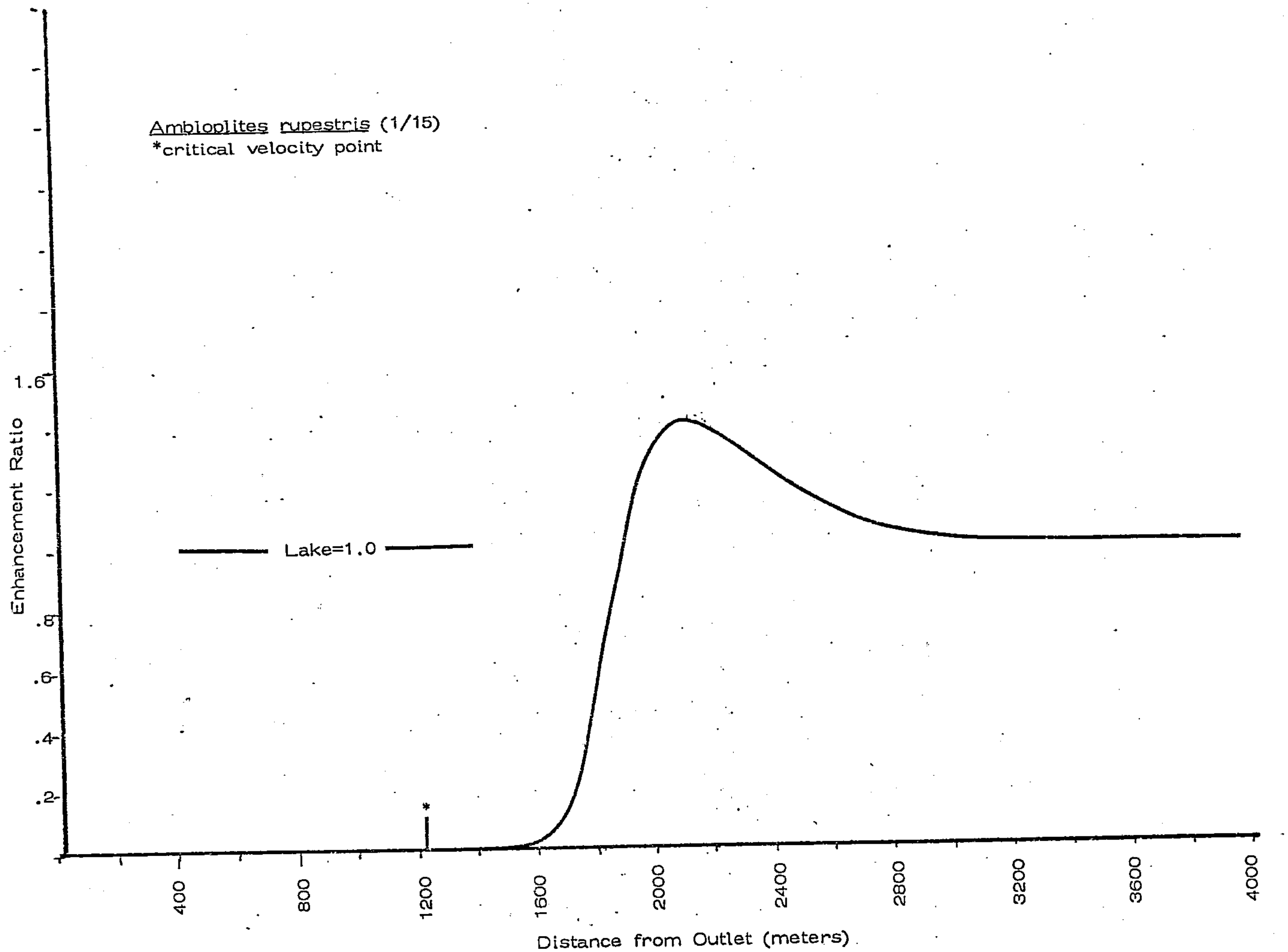
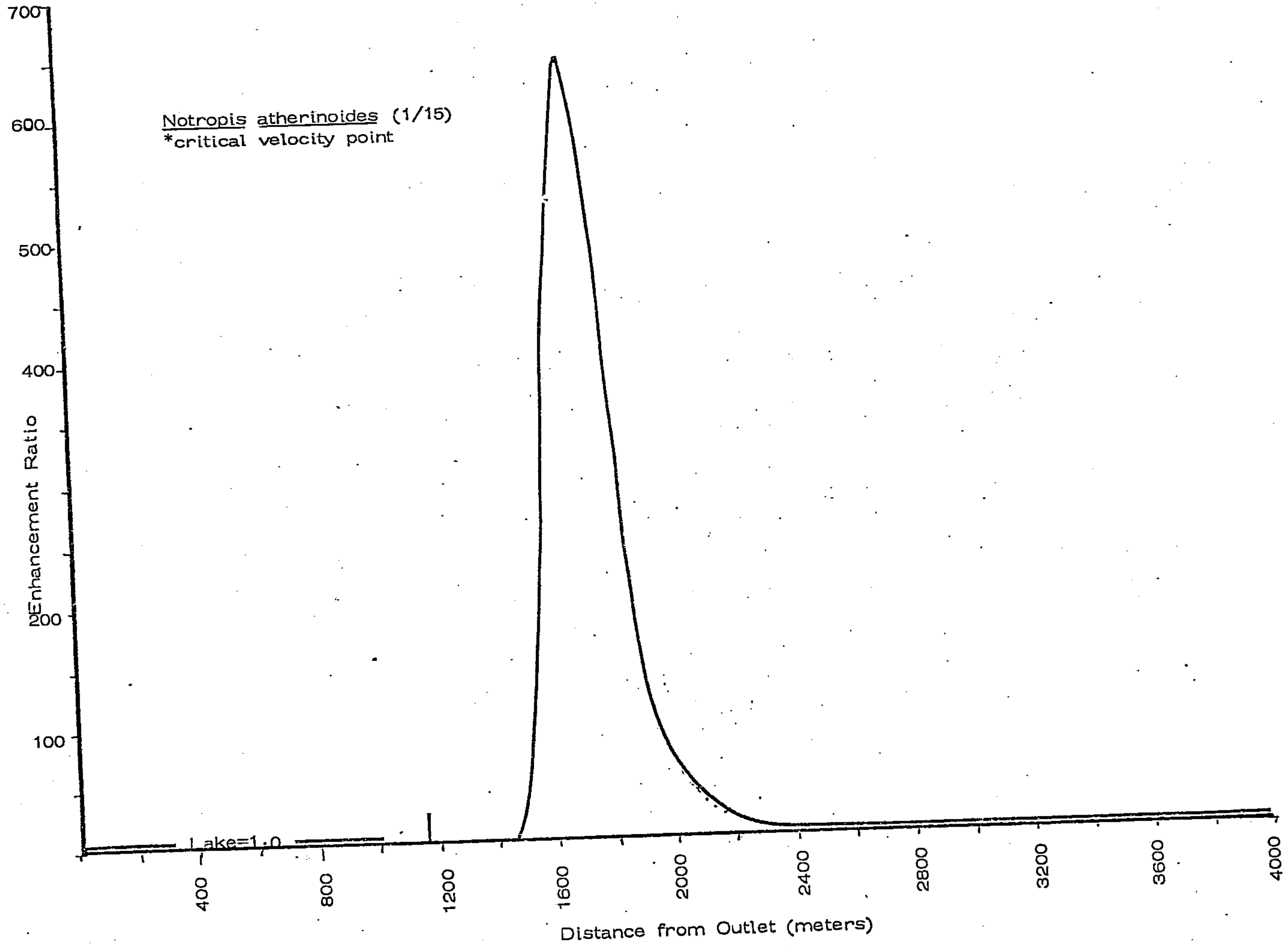


EXPECTED STEADY STATE DISTRIBUTION FOR *Ambloplites rupestris*



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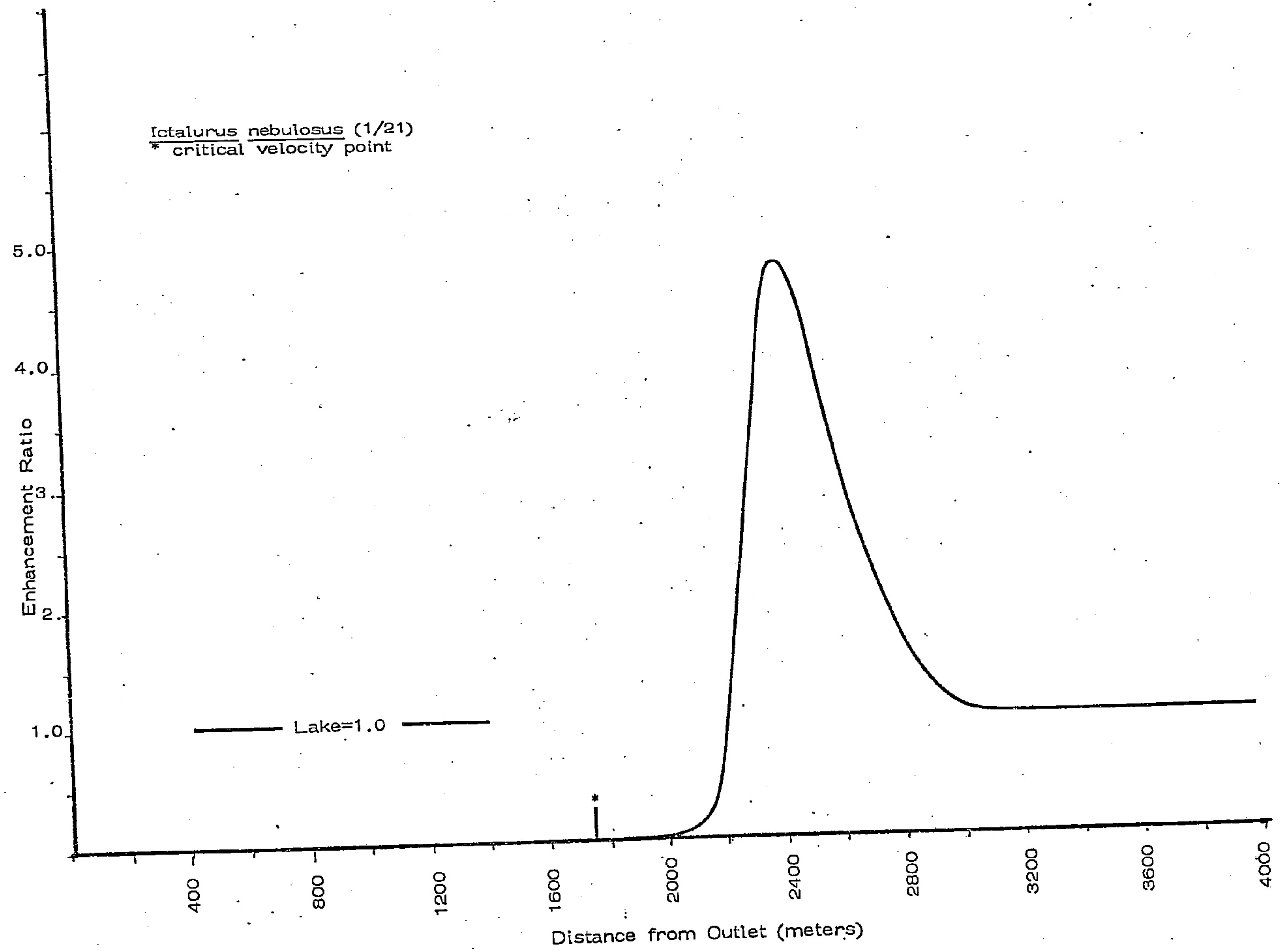
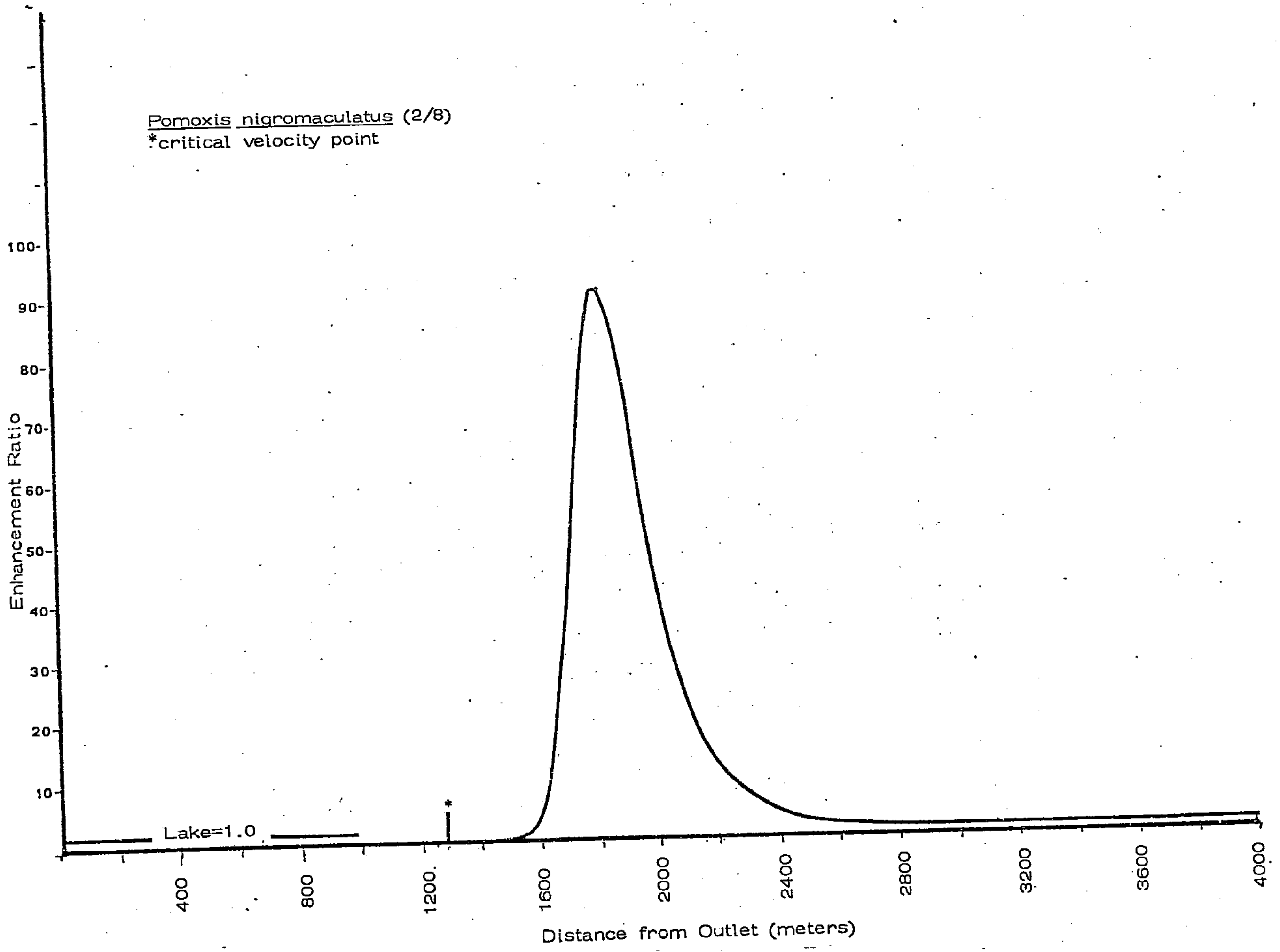


EXPECTED STEADY STATE DISTRIBUTION FOR <u>Ictalurus nebulosus</u>



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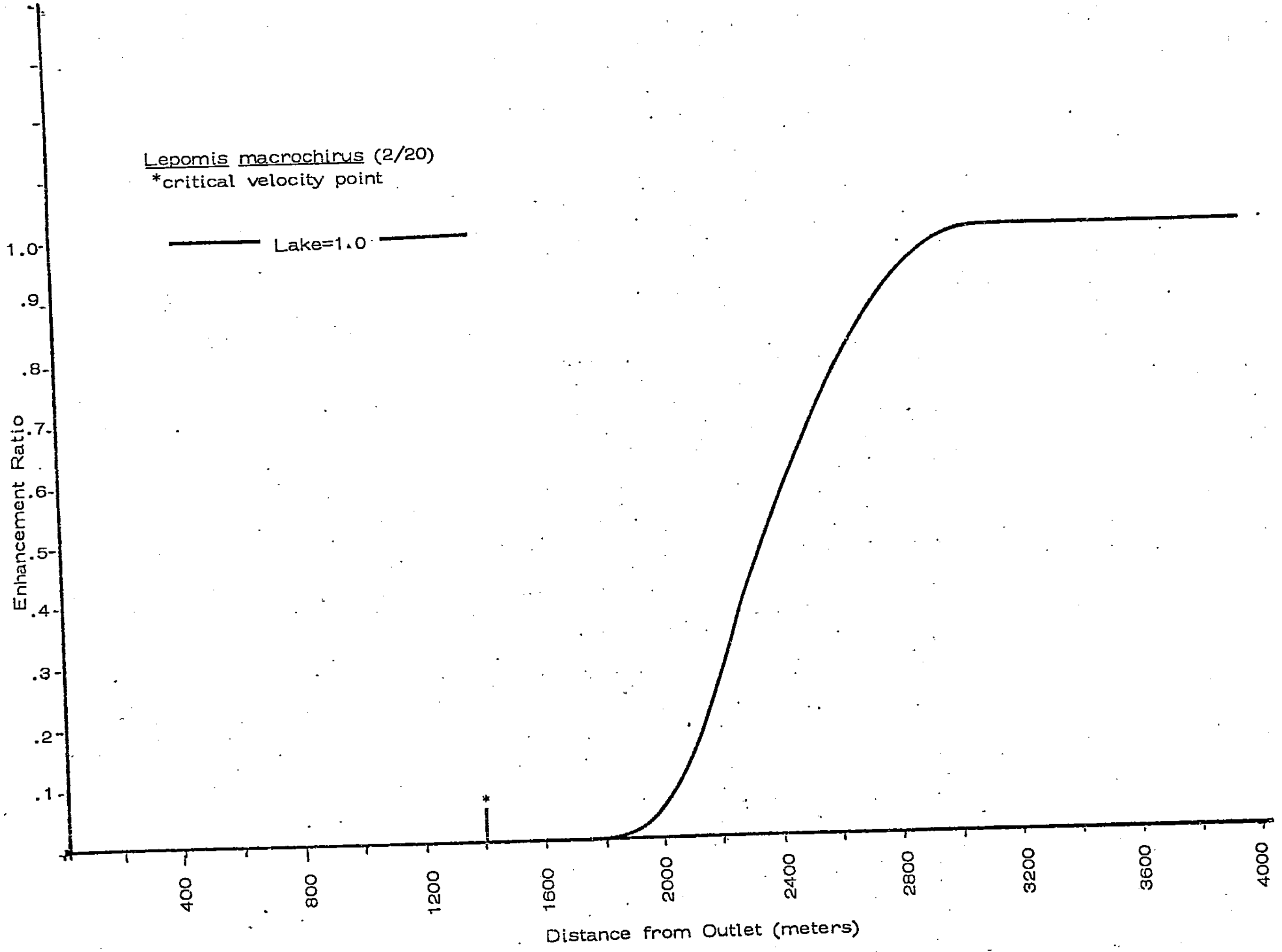
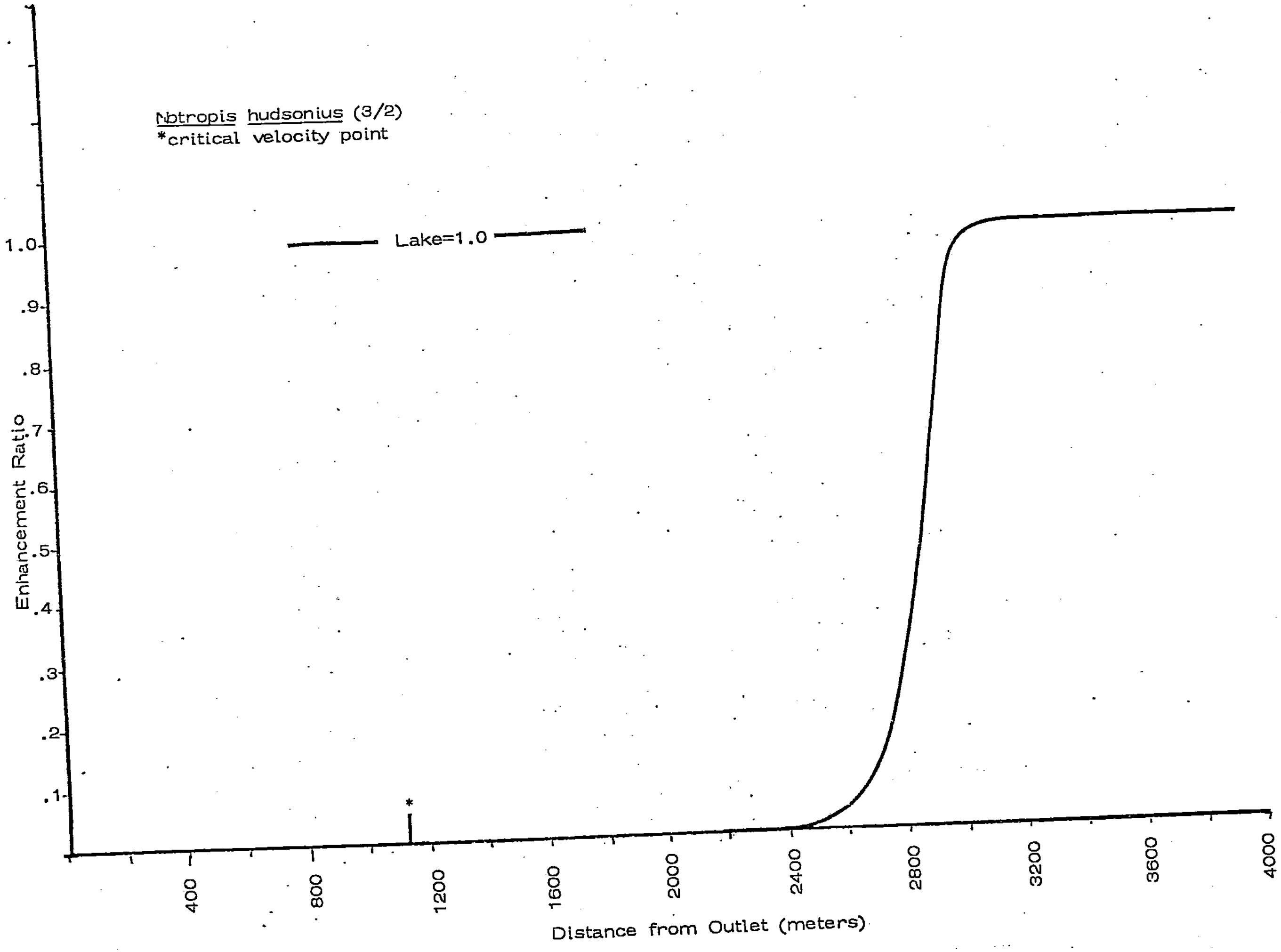


EXPECTED STEADY STATE DISTRIBUTION FOR *Lepomis macrochirus*



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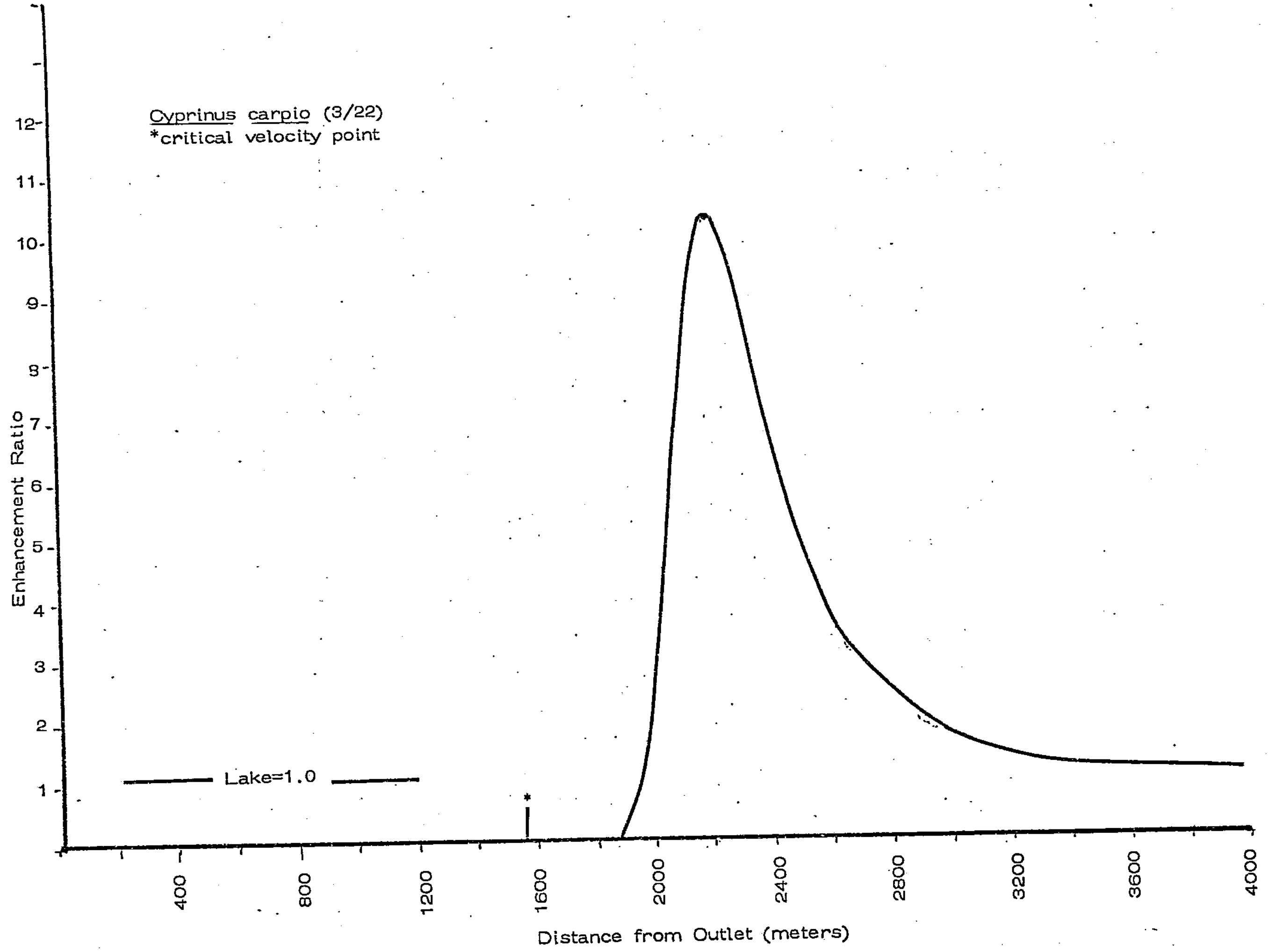

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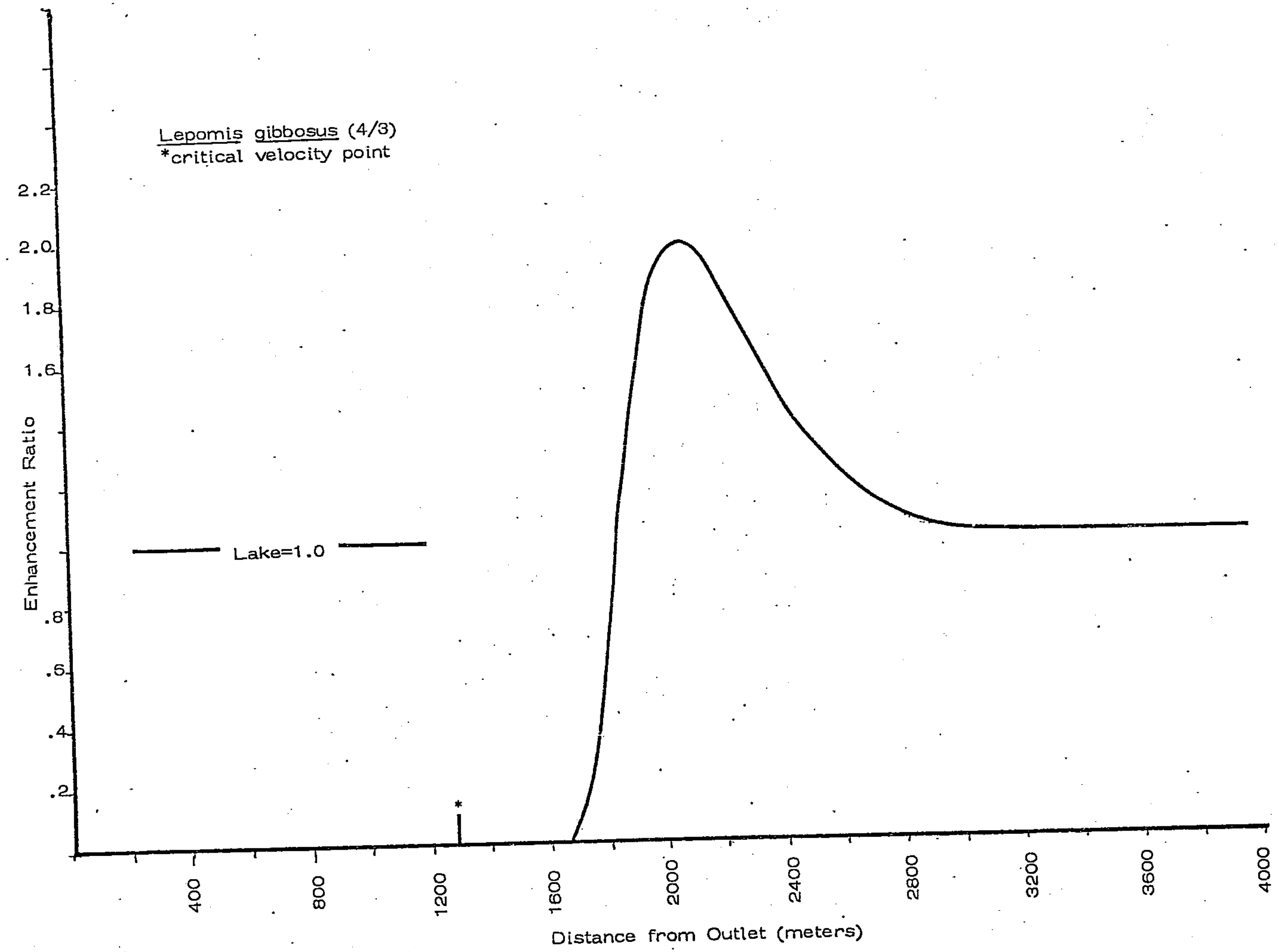

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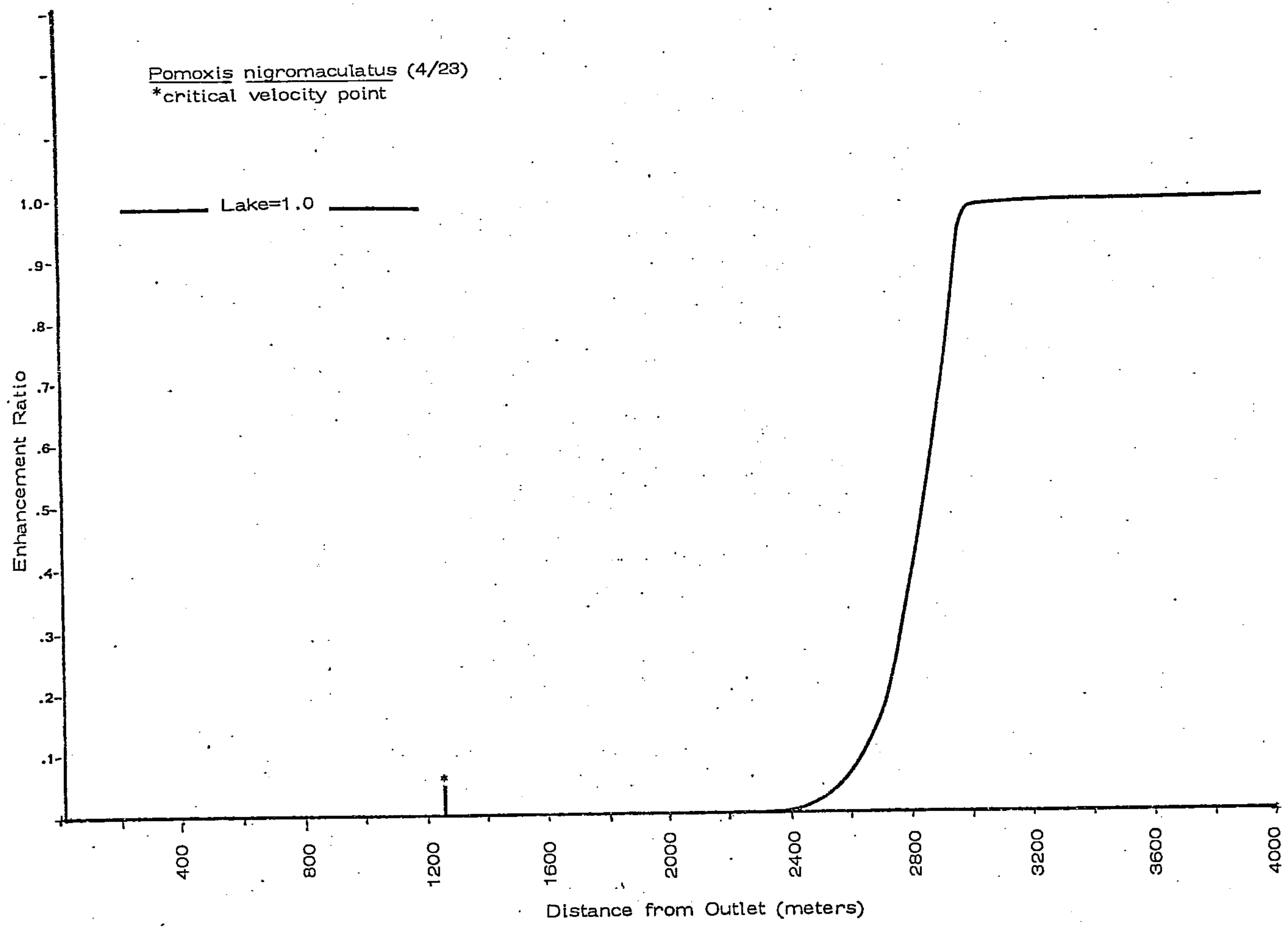

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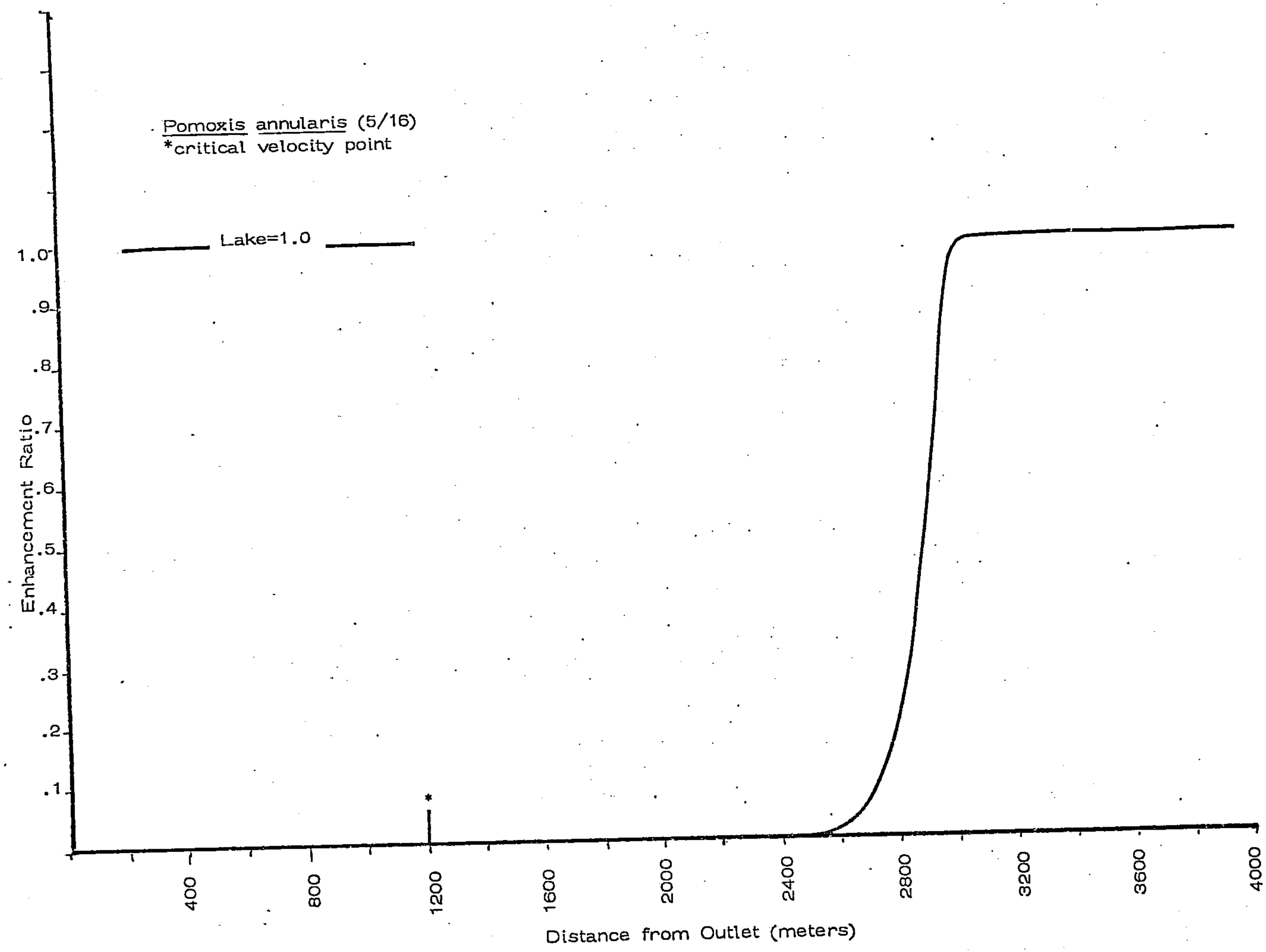

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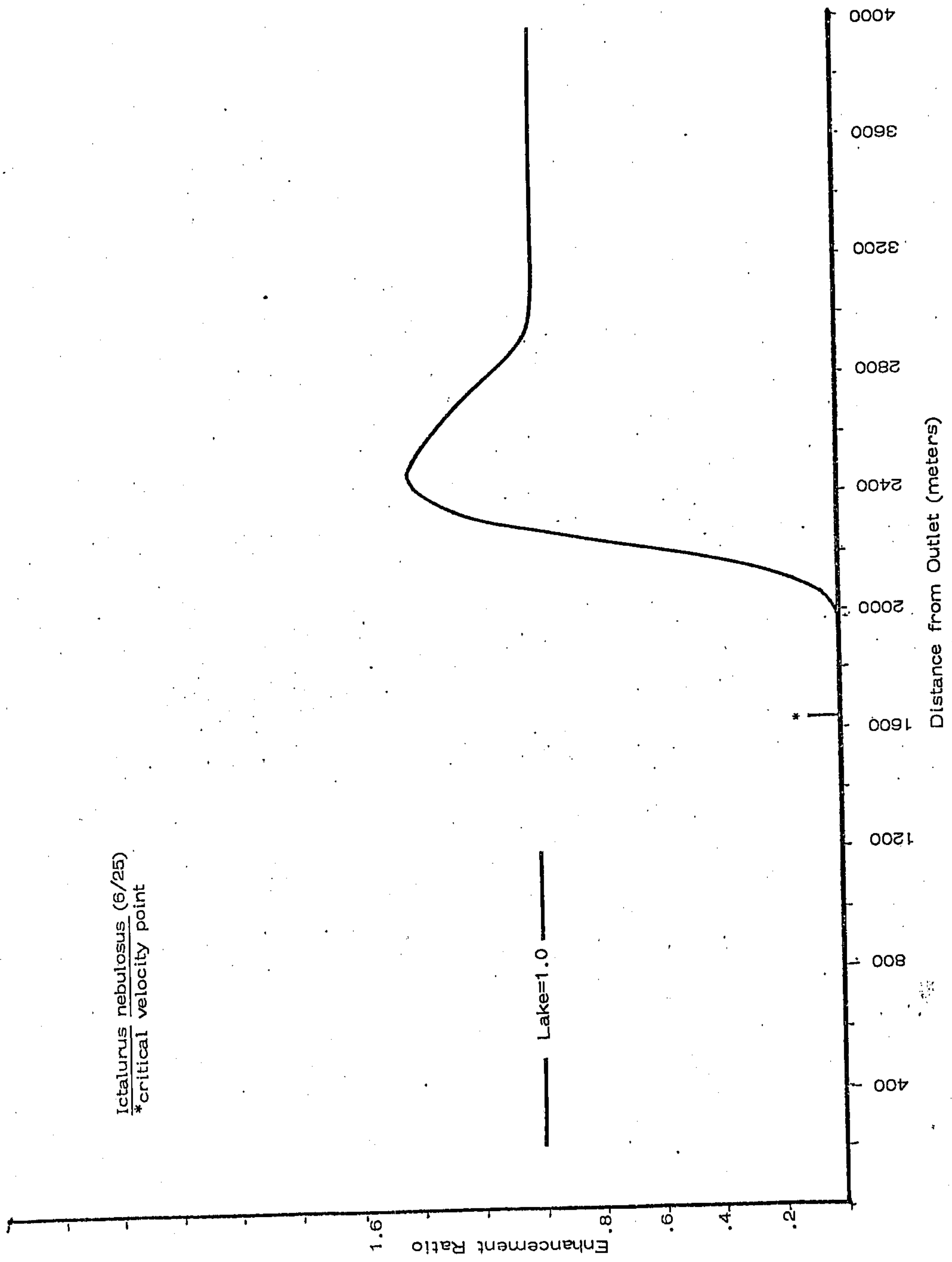

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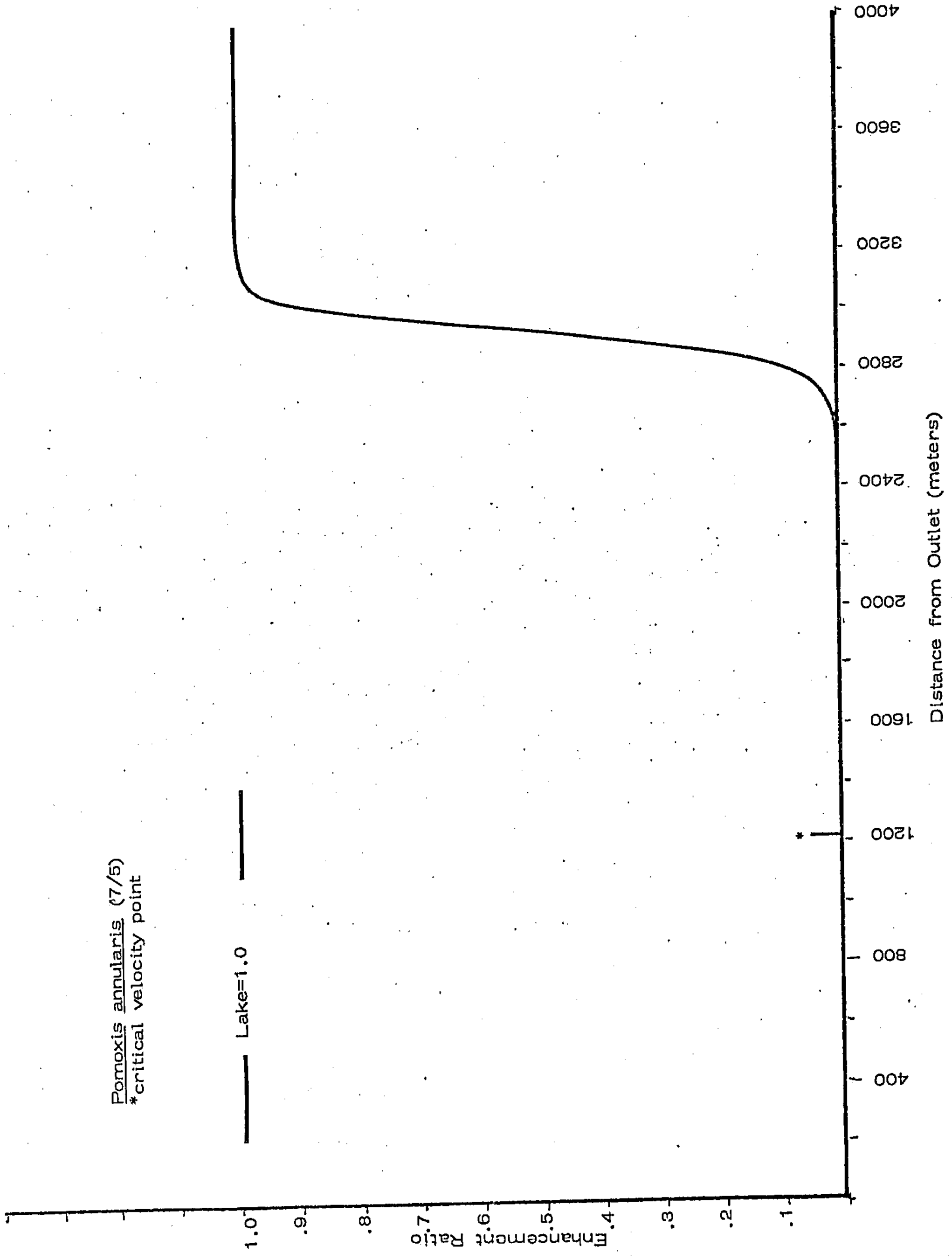
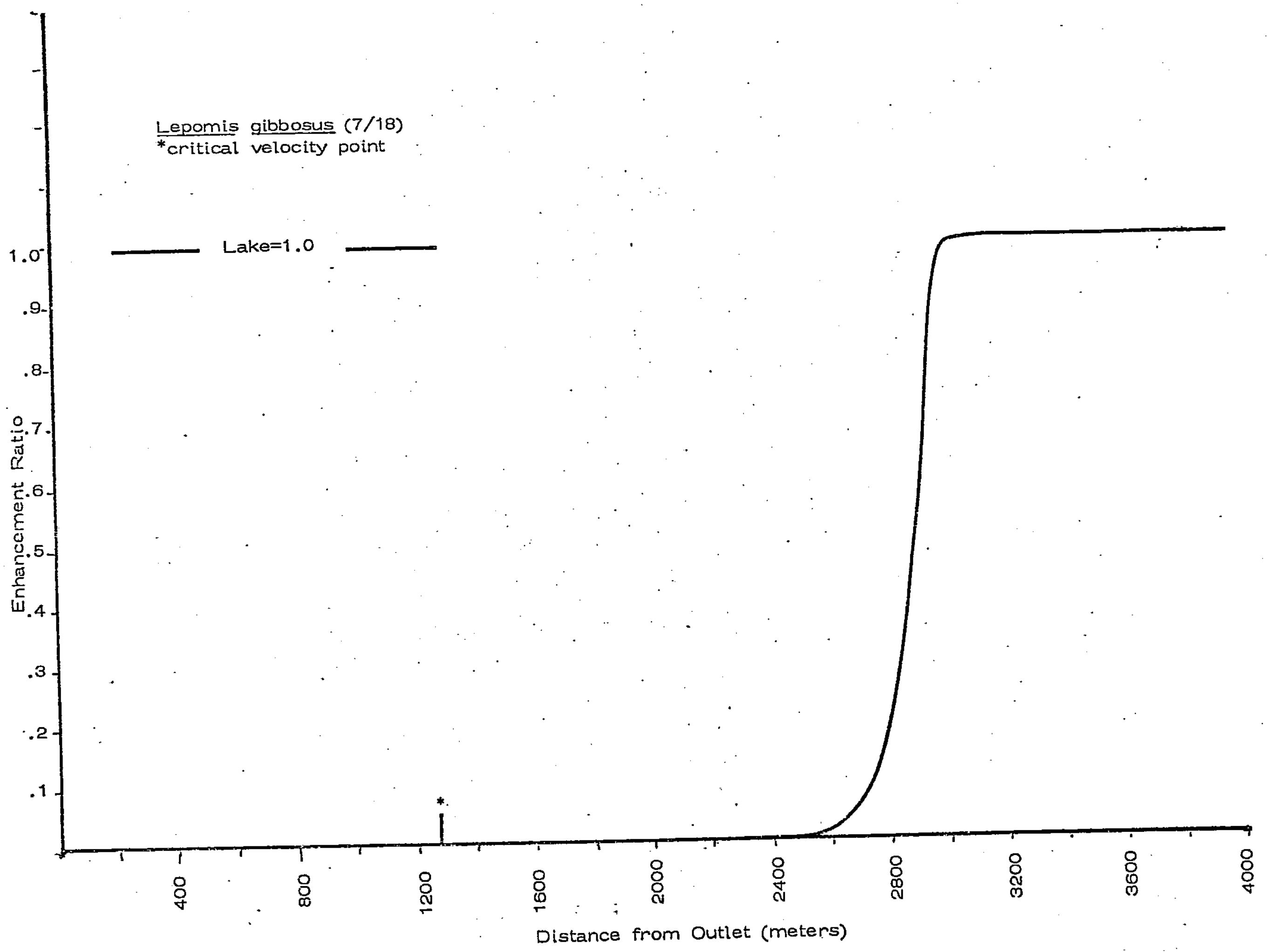
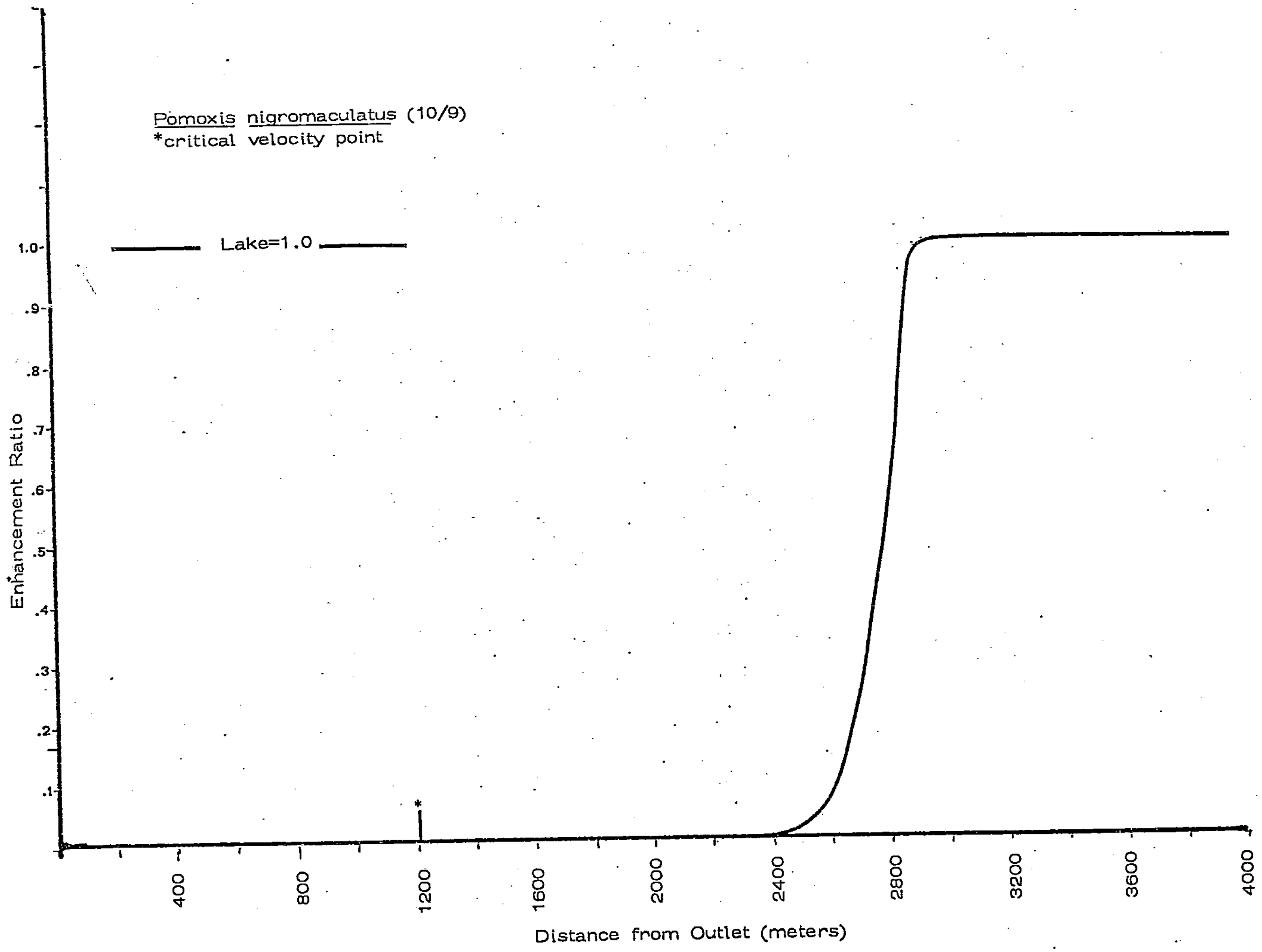


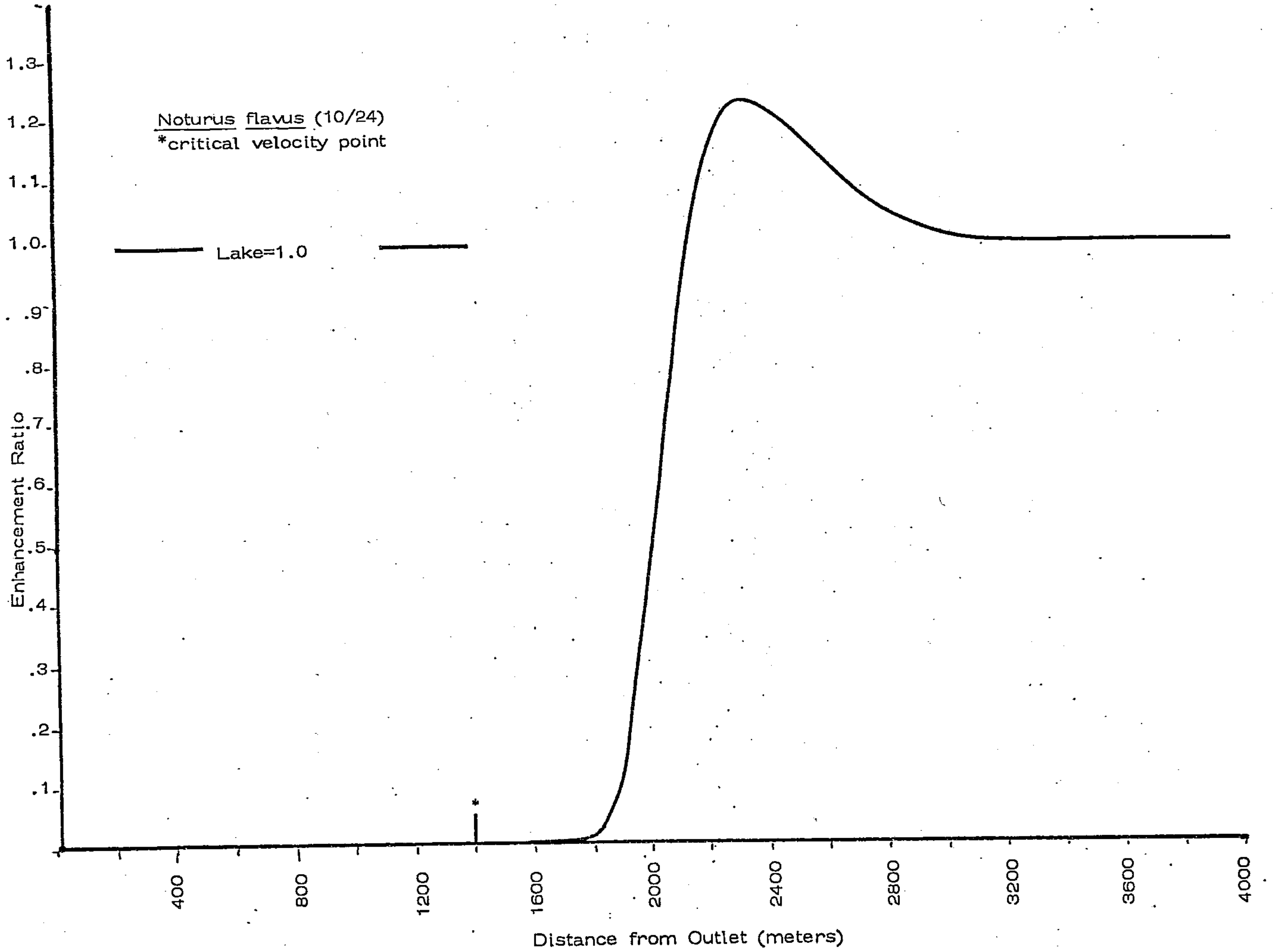
EXPECTED STEADY STATE DISTRIBUTION FOR *Pomoxis annularis*



EXPECTED STEADY STATE DISTRIBUTION FOR *Lepomis gibbosus*



EXPECTED STEADY STATE DISTRIBUTION FOR *Pomoxis* *nigromaculatus*



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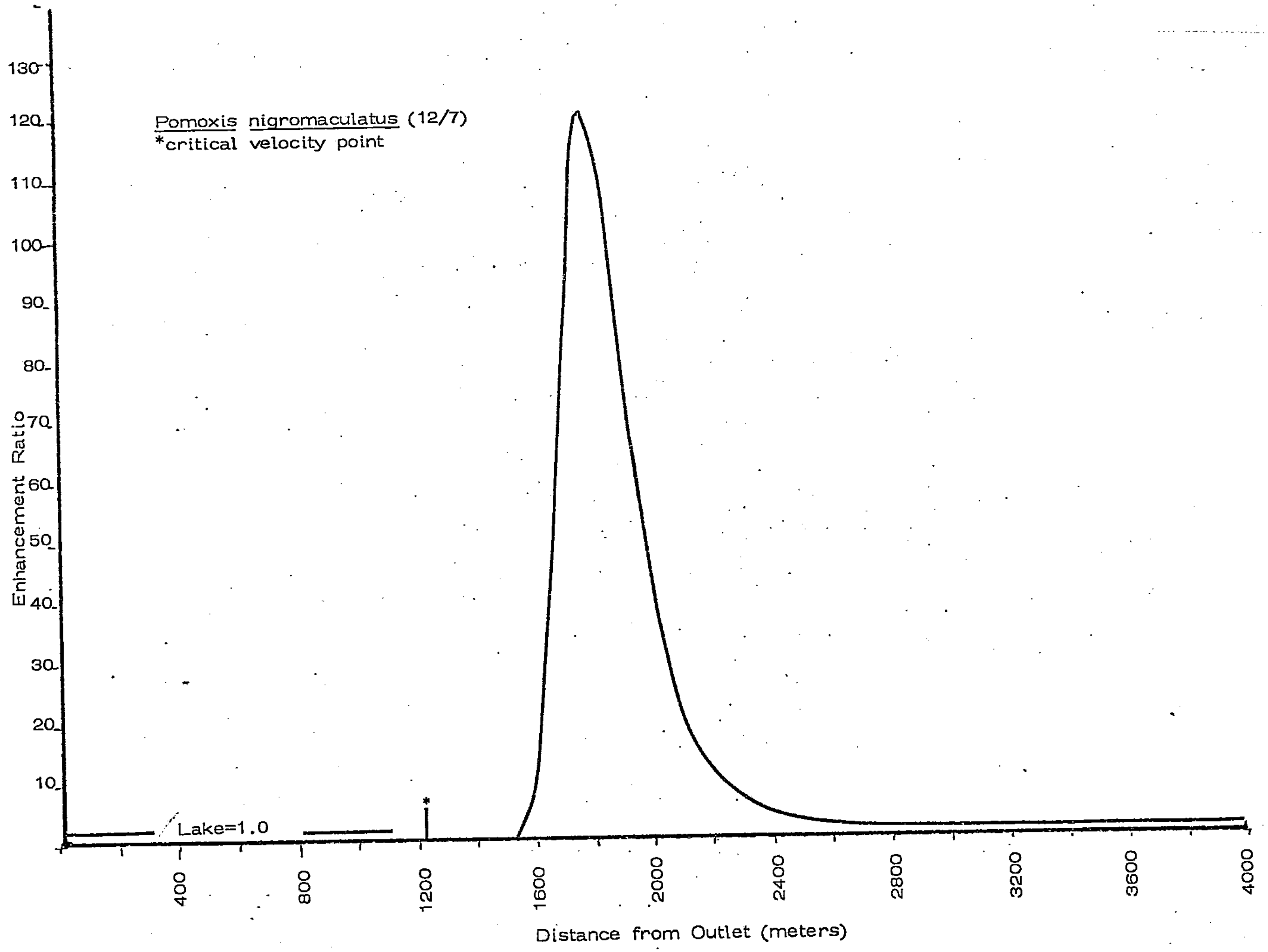
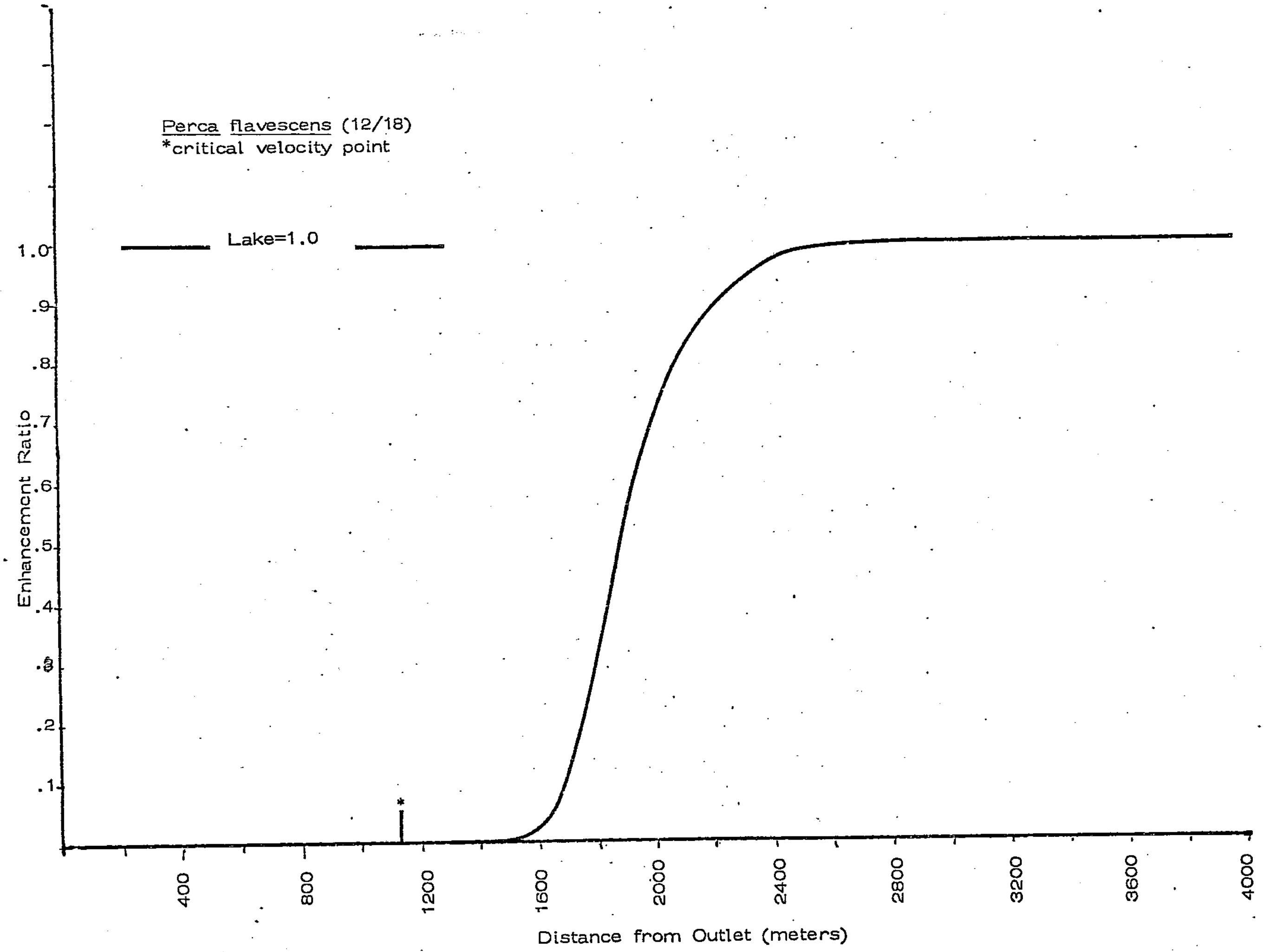


EXPECTED STEADY STATE DISTRIBUTION FOR *Pomoxis nigromaculatus*



EXPECTED STEADY STATE DISTRIBUTION FOR _Perca_ _flavescens_

APPENDIX II

EXPO. FORT

APPENDIX II

EXPO. FORT

This is the first program of two total that comprise the model system. The purpose of the program is to take a series of data points of the form (location, no. of fish) and fit the below equation to them.

$$P(x) = \frac{C}{\sqrt{2\pi}\,\sigma}\, e^{-[(x-M)^2/2\sigma^2](e^{b(x-m)}+1)/2}$$

It should be noted that in the special case where b = 0, this equation becomes the expression for a normal Gaussian distribution with a mean $\underline{M}$ and standard deviation $\underline{\sigma}$. $\underline{C}$ is a normalization constant and $\underline{b}$ will be referred to as a skewing factor.

Since the fish are essentially integer quantities, an offset factor explicitly determined is subtracted from the above expression during the fitting process.

The fitting is accomplished as follows. The offset factor is calculated as $\left(\sum^{N} \text{(normalized data)} - \sum^{N} P(x)\right)/_{N}$. A binary search is then initiated to find $\underline{b}$ by minimization of the squares of the residuals. When this minimization is accomplished, a new value of the offset factor is calculated and the iteration counter is incremented. A new $\underline{b}$ value is then determined and the process continued. Iteration is terminated in one of three ways: 1) if the value of the offset factor does not change on successive iterations, 2) if the $\sum^{N}(R^2) < 10^{-5}$, or 3) if the number of outer loop iterations exceeds 20. The maximum number of iterations of the inner loop (*b* value) is ~30. Convergence is generally rapid with minimization being attained after ~5-10 outer loop iterations for most cases.

VARIABLE LIST

variable	value	variable	value
PI	π	SUMY	$\sum Y$
SQSUM	$\sum(Y \cdot X^2)$	SUMF	$\sum P(x)$
N	no. data pairs	BINC	binary search increment (Δb)
NT	no. total fish		
AMEAN	M	G	$1/(\sigma\sqrt{2\pi})$
SQ	M^2	E	$(x - M)^2 / 2\sigma^2$
STD	σ	F	$b(x - M)$
A	offset factor	A1	$\left(\sum Y - \sum P(x)\right)/N$
B	skewing factor	SUMFUN	$\sum$ FUN
B1	OMIT	SUMF 1	$\sum$ FUN 1
KOUNT	outer loop iterations		
ST	$2\sigma^2$		

Variable	value
SUMF2	$\sum \mathrm{FUN}\,2$
E1	$(b+\Delta b)(x-M)$
E2	$(b-\Delta b)(x-M)$
D	$(x-M)^2/2\sigma^2$
C	$D(e^{b(x-M)}+1)/2$
C1	$D(e^{(b+\Delta b)(x-M)}+1)/2$
C2	$D(e^{(b-\Delta b)(x-M)}+1)/2$
FUN	$P(x)+\mathrm{offset}-Y$
FUN1	$P(x)^{+\Delta b}+\mathrm{offset}-Y$
FUN2	$P(x)^{-\Delta b}+\mathrm{offset}-Y$
PISQ	$1/\sigma\sqrt{2\pi}$
Y	(# fish at location) / total
X	location
R	residual^2

PROGRAM LISTING OF EXPO

```
'TS0359.EXPO.FORT'
      DIMENSION Y(30),X(30),R(3)
      DATA PI/3.14159265/
5     WRITE(6,200)
200   FORMAT(' ','HOW MANY DATA POINTS AND TOTAL UNITS?')
      READ(5,*) N,NT
      CALL ERRSET(207,250,-1,1,0,208)
      CALL ERRSET(241,250,-1,1,0,252)
      WRITE(6,201)
201   FORMAT(' ','ENTER POSITION AND VALUE')
      READ(5,*) (X(I),Y(I),I=1,N)
      AMEAN=0.0E0
      SQSUM=0.0E0
      DO 10 I=1,N
      Y(I)=Y(I)/NT
      AMEAN=AMEAN+Y(I)*X(I)
      SQSUM=SQSUM+Y(I)*(X(I)**2)
10    CONTINUE
      SQ=AMEAN**2
      STD=SQRT(SQSUM-SQ)
      A=0.0E0
      B=0.0E0
      B1=0.0E0
      KOUNT=0
      ST=2.0*(STD**2)
      BINCR=.1
90    SUMY=0.0E0
      SUMF=0.0E0
      G=1.0E0/(STD*SQRT(2.0*PI))
      DO 30 I=1,N
      SUMY=SUMY+Y(I)
      E=((X(I)-AMEAN)**2)/(2.0*STD**2)
      F=((X(I)-AMEAN)*B)
      SUMF=SUMF+G*EXP(-E*(EXP(F)+1.0)*.5)
30    CONTINUE
      A1=(SUMY-SUMF)/N
      IF(A1.EQ.A) GO TO 500
      A=A1
80    SUMFUN=0.0E0
      SUMF1=0.0E0
      SUMF2=0.0E0
      DO 40 I=1,N
      F=X(I)-AMEAN
      E=B*F
      E1=(B+BINCR)*F
```

(Continues)

PROGRAM LISTING OF EXPO (CON'T.)

```
      E2=(B-BINCR)*F
      D=(F**2)/ST
      C=D*(EXP(E)+1.0E0)*.5
      C1=D*(EXP(E1)+1.0E0)*.5
      C2=D*(EXP(E2)+1.0E0)*.5
      FUN=G*EXP(-C)+A-Y(I)
      FUN1=G*EXP(-C1)+A-Y(I)
      FUN2=G*EXP(-C2)+A-Y(I)
      SUMFUN=SUMFUN+FUN**2
      SUMF1=SUMF1+FUN1**2
      SUMF2=SUMF2+FUN2**2
   40 CONTINUE
      IF(SUMF1.GE.SUMFUN) GO TO 65
      B=B+BINCR
      GO TO 80
   65 IF(SUMF2.GE.SUMFUN) GO TO 70
      B=B-BINCR
      IF(ABS(SUMFUN-SUMF2).LT.1.0E-50) GO TO 90
      GO TO 80
   70 BINCR=BINCR/2.0
      IF(ABS(SUMFUN).LT.1.0E-5) GO TO 500
      IF(BINCR.LT.1.0E-10) GO TO 95
      GO.TO 80
   95 KOUNT=KOUNT+1
      IF(KOUNT.GT.20) GOTO 500
      GO TO 90
  500 WRITE(6,205) A,B,SUMFUN,KOUNT
  205 FORMAT(' ','ORDER IS: A, B, RESIDUAL**2, ITERATIONS',/' ',4G15.9)
      PISQ=1.0E0/(STD*SQRT(2.0*PI))
      DO 50 I=1,3
      R(I)=0.0E0
   50 CONTINUE
      ST=2.0*(STD**2)
      DO 60 I=1,N
      R(1)=((Y(I)-PISQ*EXP(-((X(I)-AMEAN)**2/ST)*.5*(EXP(B*
     1(X(I)-AMEAN))+1.0))-A))**2+R(1)
      R(2)=((Y(I)-PISQ*EXP(-((X(I)-AMEAN)**2/ST)*.5*(EXP((B-.1)*
     1(X(I)-AMEAN))+1.0))-A))**2+R(2)
      R(3)=((Y(I)-PISQ*EXP(-((X(I)-AMEAN)**2/ST)*.5*(EXP((B+.1)*
     1(X(I)-AMEAN))+1.0))-A))**2+R(3)
   60 CONTINUE
      WRITE(6,203) AMEAN,STD,B,R(1),R(2),R(3)
  203 FORMAT(' ','ORDER: MEAN, STD.DEV., B, R(B), R(B-.1), R(B+.1)',
     1/' ',6G12.6)
      GO TO 5
      END
```

APPENDIX III

FISHES , FORT

APPENDIX III

FISHES . FORT

This is the second program of the set and is the actual model of fish behavior and distribution. It consists of a Monte-Carlo simulation of individual fish motions in a thermal gradient with current effects. The probabilities of transition to a point closer to the source, to a point more distant from the source and of no transition in a time increment are calculated by:

$$P_{closer} = \lambda(i, v) \cdot \Delta t$$

$$P_{further} = \mu(i, v) \cdot \Delta t$$

$$P_{stay} = (1 - P_{closer}) \cdot (1 - P_{further})$$

and

$$P_{up} = \frac{P_{closer}}{\sum P}$$

$$P_{down} = \frac{P_{further}}{\sum P}$$

$$P_{stay} = \frac{P_{stay}}{\sum P}$$

A random number generater is then used to determine which transition occurs. After the transition the acclimation temperature is re-evaluated and the loop continues for the next Δt until the specified simulated time has elapsed. This is then repeated until a specified number of fish have been simulated. The final location at the end of each simulation period is recorded for each fish. The results are then normalized to yield the occupation probabilities. Steady state conditions are then calculated according to the method given in the program users' manual.

VARIABLE LIST

Variable	Value
TM	acclimation temperature with time
A, B, D, F	constants for λ and μ
TLAKE	lake temperature
TPREF	final preferred temperature
TMAX	maximum temperature available to fish
OMEGA	frequency of temperature oscillation
BETA	factor describing spread of temperature peaks with distance from source
DELTIM	Δt
DTEMP	magnitude of temperature fluctuation at source
TOUT	maximum temperature of source

Variable	Value
XFAL	exponential fall-off rate of temperature and current with distance from source (normally .0025)
EPIS	rate of change of acclimation temperature
SKEW	skewing factor of acclimation temperature distribution
COUT	maximum current speed at source
STD	σ in acclimation temperature distribution
BOXLEN	compartment size
R	start value for random number generator
NOFISH	number of fish to be simulated
RUNTIM	time period to be simulated
VS	swimming speed
ITIM	number of Δt increments in RUNTIM
LOC	position of fish at time
PI, IP	used to calculate random number
PROB	random number ($0 \leq \text{PROB} \leq 1$)
TD	temperature of next lowest compartment

Variable	Value
TLOC	temperature at LOC
PUP	probability of going from LOC to LOC-1
PDOWN	probability of going from LOC to LOC+1
PSTAY	probability of no transition
SUMP	$\sum P$
POSITN	array of final locations
LOCZRO	Location of critical velocity point
DLTFTR	time scaling factor
TIMINT	1/10 × RUNTIM
EQPT	critical velocity point in meters distance
ADAPT	adaptation time
SUBTIM	time of next observation period
INDX	time interval counter (1-10)
CURNT	current in occupied box
AL, AM	rates for current and velocity gradients in same direction
AL2, AM2	rates for current and velocity gradients in opposite directions
FACTIM	$\Delta t/$ unit length

Variable	Value
ITAB	first position table to be printed
TESTIM	time at which the INDXth observation was made
SSPSUM	steady state probability sum
IS	start location for steady state tables
IL	length of tables
ER	enhancement ratios
PSS	steady state probabilities
TIMSUM	elapsed simulation time

Subprogram List

SUBPROGRAM LIST

Name	Value Returned
ALAM	λ(LOC, V), μ(LOC, V)
TFUNC	temperature at LOC with time
CUR	current speed at LOC

Errata: In line 2120, the expression: J*DELTIM should be replaced by TIMSUM, and TIMSUM should be added to COMMON. J can be deleted from COMMON. This will correct the expression which generates the thermal non-linearities and will make the time scale of fluctuation consistent with the remainder of the program. It has no effect on the gradient when DTEMP is zero.

PROGRAM LISTING OF FISHES

```
FISHES.FORT
      DIMENSION POSITN(500,10),PSS(500),ER(500)
      COMMON/B1/TM,TLAKE,TPREF,TMAX,J,OMEGA,BETA,DELTIM,
     1LOCZRO,DTEMP,TOUT,XFAL,EPIS,SKEW,COUT,STD,BOXLEN
      CALL ERRSET(252,250,-1,1,0,254)
      CALL ERRSET(207,300,-1,1,0,208)
      PROB=.0123456789
      WRITE(6,100)
  100 FORMAT(' ','ENTER:NOFISH,TLAKE,TPREF,EPIS,SKEW,STD')
      READ(5,*) NOFISH,TLAKE,TPREF,EPIS,SKEW,STD
      WRITE(6,101)
  101 FORMAT(' ','ENTER:RUNTIM,TOUT,DTEMP,OMEGA,BETA,COUT,XFAL')
      READ(5,*) RUNTIM,TOUT,DTEMP,OMEGA,BETA,COUT,XFAL
      WRITE(6,102)
  102 FORMAT(' ','ENTER:VS,DLTFTR,BOXLEN')
      READ(5,*) VS,DLTFTR,BOXLEN
    5 TIMINT=RUNTIM/10.
      WRITE(6,103)
  103 FORMAT(' ','PROGRAM EXECUTING')
      EQPT=-ALOG(VS/COUT)/XFAL
      LOCZRO=EQPT/BOXLEN
      IF(LOCZRO.LT.1) LOCZRO=1
      KNTR=0
      DO 15 J=1,10
      DO 10 K=1,500
      POSITN(K,J)=0.0E0
   10 CONTINUE
   15 CONTINUE
      DO 20 I=1,NOFISH
      ADAPT=0.0E0
      SUBTIM=TIMINT
      INDX=1
      LOC=I-500*((I-1)/500)
      IF(LOC.GT.500) LOC=500
      IF(LOC.LT.1) LOC=1
      TMAX=TFUNC(LOC)
      TM=TLAKE
      TIMSUM=0.0E0
   30 PI=1.010010001/PROB
      IP=PI
      PROB=PI-IP
      IF(PROB.LT.1.E-9) PROB=1.E8*PROB+.070070007
      CURNT=CUR(LOC)
      AL=ALAM(LOC,LOC-1,VS)
      AM=AMU(LOC,LOC+1,VS)
      AL2=ALAM(LOC,LOC+1,VS)
      AM2=AMU(LOC,LOC-1,VS)
      TD=TFUNC(LOC+1)
      TLOC=TFUNC(LOC)
      IF(TD.GT.TLOC) GO TO 32
      DELTIM=(BOXLEN/(AL-CURNT))*DLTFTR
```

(Continues)

PROGRAM LISTING OF FISHES (CON'T.)

```
      IF(AM+CURNT.GT.AL-CURNT) DELTIM=(BOXLEN/(AM+CURNT))*DLTFTR
      FACTIM=DELTIM/BOXLEN
      PUP=(AL-CURNT)*FACTIM
      PDOWN=(AM+CURNT)*FACTIM
      IF(PUP.LT.0.0E0) PUP=0.0E0
      IF(PDOWN.LT.0.0E0) PDOWN=0.0E0
      PSTAY=(1.0-PUP)*(1.0-PDOWN)
      IF(PSTAY.LT.0.0E0) PSTAY=0.0E0
      SUMP=PUP+PDOWN+PSTAY
      PUP=PUP/SUMP
      PDOWN=PDOWN/SUMP
      PSTAY=PSTAY/SUMP
      GO TO 36
   32 DELTIM=(BOXLEN/(AM2-CURNT))*DLTFTR
      IF(AL2+CURNT.GT.AM2-CURNT) DELTIM=(BOXLEN/(AL2+CURNT))*DLTFTR
      FACTIM=DELTIM/BOXLEN
      PUP=(AM2-CURNT)*FACTIM
      PDOWN=(AL2+CURNT)*FACTIM
      IF(PUP.LT.0.0E0) PUP=0.0E0
      IF(PDOWN.LT.0.0E0) PDOWN=0.0E0
      PSTAY=(1.0-PUP)*(1.0-PDOWN)
      IF(PSTAY.LT.0.0E0) PSTAY=0.0E0
      SUMP=PUP+PDOWN+PSTAY
      PUP=PUP/SUMP
      PDOWN=PDOWN/SUMP
      PSTAY=PSTAY/SUMP
   36 IF(PROB.LE.PUP+PDOWN) GO TO 37
      GO TO 39
   37 IF(PROB.LE.PUP) GO TO 38
      LOC=LOC+1
      GO TO 39
   38 LOC=LOC-1
   39 IF(LOC.GT.500) LOC=500
      IF(LOC.LT.1) LOC=1
      IF(ALAM(LOCZRO+1,LOCZRO,VS).GE.CUR(LOCZRO+2).AND.
     1TM.GE.TFUNC(LOCZRO)) GO TO 35
      ADAPT=ADAPT+DELTIM
      TM=TPREF-(TPREF-TLAKE)*EXP(-EPIS*ADAPT)
   35 TIMSUM=TIMSUM+DELTIM
      KNTR=KNTR+1
      IF(TIMSUM.LT. SUBTIM) GO TO 30
      POSITN(LOC,INDX)=POSITN(LOC,INDX)+1.0E0
      INDX=INDX+1
      SUBTIM=SUBTIM+TIMINT
      IF(INDX.LE.10) GO TO 30
   20 CONTINUE
      WRITE(6,215)
  215 FORMAT(' ','DO YOU WANT THE POSITION TABLES?')
      READ(5,150) ANS
      IF(ANS.NE.YES) GO TO 42
```

(Continues)

PROGRAM LISTING OF FISHES (CON'T.)

```
      WRITE(6,216)
 216  FORMAT(' ','ENTER THE NUMBER OF THE FIRST POSITION TABLE TO BE ',
     1'PRINTED (1 TO 10)')
      READ(5,*) ITAB
      DO 45 JK=ITAB,10
      DO 40 K=1,500
      POSITN(K,JK)=POSITN(K,JK)/NOFISH
 40   CONTINUE
      TESTIM=JK*TIMINT
      WRITE(6,208) TESTIM
 208  FORMAT(' ',/' ','OBSERVATION TIME= ',G14.8)
      WRITE(6,200) (POSITN(K,JK),K=1,500)
  45  CONTINUE
  42  WRITE(6,207) KNTR
  207 FORMAT(' ','TOTAL NUMBER OF ITERATIONS= ',I8)
      WRITE(6,213) TM
 213  FORMAT(' ','INTERNAL PREFERED TEMPERATURE=',G14.8)
      WRITE(6,214) ADAPT
 214  FORMAT(' ','TIME TO STEADY STATE RATES=',G14.8)
      WRITE(6,201)
 201  FORMAT(' ',2(/' '),'DO YOU WISH TO CONTINUE?')
      READ(5,150) ANS
 150  FORMAT(A3)
      DATA YES/'YES'/
      IF (ANS.NE.YES) GO TO 50
      WRITE(6,202)
202   FORMAT(' ','ENTER RUNTIM,DLTFTR,NOFISH,BOXLEN')
      READ(5,*) RUNTIM,DLTFTR,NOFISH,BOXLEN
      GO TO 5
 50   WRITE(6,209)
  209 FORMAT(' ','DO YOU WANT THE TEMPERATURE TABLE?')
      READ(5,150) ANS
      IF(ANS.NE.YES) GO TO 70
      DO  60 KK=1,500
      POSITN(KK,1)=TFUNC(KK)
  60  CONTINUE
      WRITE(6,206) (POSITN(JK,1),JK=1,500)
206   FORMAT(' ',20F4.1)
 200  FORMAT(' ',20F4.3)
  70  WRITE(6,212)
 212  FORMAT(' ','DO YOU WANT THE FINAL RATES?')
      READ(5,150) ANS
      IF(ANS.NE.YES) GO TO 58
      WRITE(6,210)
 210  FORMAT(' ',1X,'LOC',3X,'TEMP',4X,'CURRENT',9X,'LAMDA',11X,'MU',
     114X,'LAMDA-MU')
      DO 65 I=LOCZRO,495,5
      T=TFUNC(I)
      V=CUR(I)
      AL=ALAM(I,I-1,VS)-V
```

(Continues)

PROGRAM LISTING OF FISHES (CON'T.)

```
      AM=AMU(I,I+1,VS)+V
      DIF=AL-AM
      WRITE(6,211) I,T,V,AL,AM,DIF
 211  FORMAT(' ',1X,I4,2X,F6.3,2X,G14.8,2X,G14.8,2X,G14.8,2X,G14.8)
 65   CONTINUE
  58  WRITE(6,217)
 217  FORMAT(' ',/' ','DO YOU WANT THE STEADY STATE PROBABILITIES AND ',
     1'ENHANCEMENT RATIOS?')
      READ(5,150) ANS
      IF(ANS.NE.YES) GOTO 75
      SSPSUM=0.0E0
      IS=LOCZRO+2
      IL=499-LOCZRO
      ER(500)=1.0E0
      DO 52 KK=1,IL
      IK=500-KK
      IKP1=501-KK
      ER(IK)=((ALAM(IKP1,IK,VS)-CUR(IKP1))/(AMU(IK,IKP1,VS)+CUR(IK)))*
     1ER(IKP1)
      IF(ER(IK).LE.0.0E0) ER(IK)=1.0E0
      SSPSUM=SSPSUM+ER(IK)
  52  CONTINUE
      DO 56 L=IS,500
      PSS(L)=ER(L)/SSPSUM
  56  CONTINUE
      WRITE(6,218)
 218  FORMAT(' ',1X,'LOCATION',3X,'PROBABILITY',6X,'ENHANCEMENT',
     1' RATIO')
      ILL=LOCZRO+5
      WRITE(6,219) (L,PSS(L),ER(L),L=ILL,495,5)
 219  FORMAT(' ',1X,I4,6X,G14.8,6X,G14.8)
 75   STOP
      END
      FUNCTION ALAM(L,L2,V)
      COMMON/B1/TM,TLAKE,TPREF,TMAX,J,OMEGA,BETA,DELTIM,
     1LOCZRO,DTEMP,TOUT,XFAL,EPIS,SKEW,COUT,STD,BOXLEN
      DT=TFUNC(L)-TM
      STDSQ=4.0*(STD**2)

      ILOC=LOCZRO
      C=ABS(TFUNC(ILOC)-TFUNC(ILOC+(L2-L)))
      IF(C.EQ.0.0E0) C=1.E-60
  10  B=ABS(TFUNC(L)-TFUNC(L2))/C
  15  ALAM=V/(1.0+EXP(B*((DT*ABS(DT))/STDSQ)*(EXP(SKEW*DT)+1.0E0)))
      RETURN
      ENTRY AMU(L,L2,V)
      DT=TFUNC(L)-TM
      STDSQ=4.0*(STD**2)

      ILOC=LOCZRO
```

(Continued)

PROGRAM LISTING OF FISHES (CON'T.)

```
      C=ABS(TFUNC(ILOC)-TFUNC(ILOC+(L2-L)))
      IF(C.EQ.0.0E0) C=1.E-60
   20 B=ABS(TFUNC(L)-TFUNC(L2))/C
   25 AMU=V/(1.0+EXP(-B*((DT+ABS(DT))/STDSQ)*(EXP(SKEW*DT)+1.0E0)))
      RETURN
      END
      FUNCTION TFUNC(K)
      COMMON/B1/TM,TLAKE,TPREF,TMAX,J,OMEGA,BETA,DELTIM,
     1LOCZRO,DTEMP,TOUT,XFAL,EPIS,SKEW,COUT,STD,BOXLEN
      AMP=.5*DTEMP*EXP(-XFAL*BOXLEN*K)
      TAVG=TLAKE+(TOUT-TLAKE)*EXP(-XFAL*BOXLEN*K)-AMP
      TFUNC=AMP*SIN((OMEGA*J*DELTIM+EXP(BETA*K*BOXLEN)*BOXLEN*K)/
     16.2831854)+TAVG
      RETURN
      END
      FUNCTION CUR(I)
      COMMON/B1/TM,TLAKE,TPREF,TMAX,J,OMEGA,BETA,DELTIM,
     1LOCZRO,DTEMP,TOUT,XFAL,EPIS,SKEW,COUT,STD,BOXLEN
      CUR=COUT*EXP(-XFAL*I*BOXLEN)
      RETURN
      END
```

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